



Rapid Refresh / HRRR

Work toward NCEP Q3 2015 NCEP operational upgrade

NOAA ESRL GSD

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Rapid Refresh version 3
High Resolution Rapid Refresh v2

Scheduled implementation Q3 2015

- Upgrades: **Thompson aerosol-aware MP, Enhancements to G-F cum. param. (RAP), MYNN PBL, RUC LSM, sat. radiance BC, assim. mesonet, Vr, LTG**

- Improvement over RAPv2 / HRRR v1
Reduced warm season afternoon/evening low-level warm/dry bias. Improved upper-air / storm environmental fields / storm forecasts



Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Rapid Refresh and HRRR

NOAA hourly updated models

13km Rapid Refresh (RAP) (mesoscale)

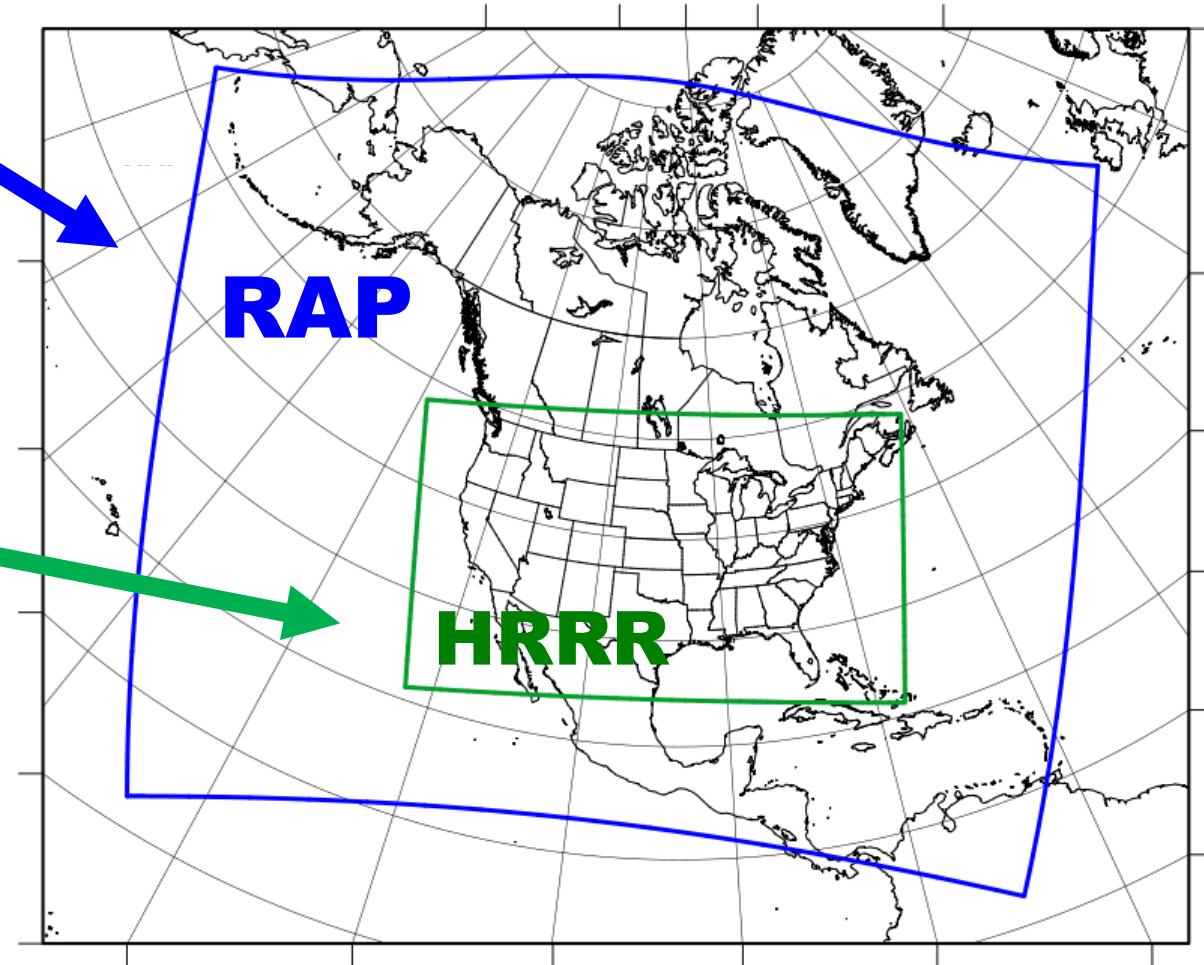
Version 2 -- NCEP implement 25 Feb 2014

**Version 3 – GSD
Planned NCEP – Q3 2015**

3km High Resolution Rapid Refresh (HRRR) (storm-scale)

Initial -- NCEP implement 30 Sept 2014

**Version 2 – GSD
Planned NCEP – Q3 2015**



RAP and HRRR R2O Schedule

	RAP		HRRR	
	Experimental	Operational	Experimental	Operational
2011	Jan	RAP	RUC	HRRR
	Feb	RAP	RUC	HRRR
	Mar	RAP	RUC	HRRR
	Apr	RAPv1 Install	RUC	HRRR
	May	RAPv1	RUC	HRRR
	Jun	RAPv1	RUC	HRRR
	Jul	RAPv1 Update	RUC	HRRR
	Aug	RAPv1	RUC	HRRR
	Sep	RAPv1	RUC	HRRR
	Oct	RAPv1	RUC	HRRR
	Nov	RAPv1	RUC	HRRR
	Dec	RAPv1	RUC	HRRR
2012	Jan	RAPv1	RUC	HRRR
	Feb	RAPv1	RUC	HRRR
	Mar	RAPv2 Install	RUC	HRRR
	Apr	RAPv2	RUC	HRRR
	May	RAPv2	RAPv1	HRRR
	Jun	RAPv2	RAPv1	HRRR
	Jul	RAPv2	RAPv1	HRRR
	Aug	RAPv2	RAPv1	HRRR
	Sep	RAPv2	RAPv1	HRRR
	Oct	RAPv2	RAPv1	HRRR
	Nov	RAPv2	RAPv1	HRRR
	Dec	RAPv2	RAPv1	HRRR
2013	Jan	RAPv2	RAPv1	HRRR
	Feb	RAPv2	RAPv1	HRRR
	Mar	RAPv2	RAPv1	HRRR
	Apr	RAPv2 Update	RAPv1	HRRRv1 Install
	May	RAPv2	RAPv1	HRRRv1
	Jun	RAPv2	RAPv1	HRRRv1
	Jul	RAPv2	RAPv1	HRRRv1
	Aug	RAPv2	RAPv1	HRRRv1
	Sep	RAPv2	RAPv1	HRRRv1
	Oct	RAPv2	RAPv1	HRRRv1
	Nov	RAPv2	RAPv1	HRRRv1
	Dec	RAPv2	RAPv1	HRRRv1
2014	Jan	RAPv2	RAPv1	HRRRv1
	Feb	RAPv2	RAPv2 Implement	HRRRv1
	Mar	RAPv2	RAPv2	HRRRv1
	Apr	RAPv3 Install	RAPv2	HRRRv2 Install
	May	RAPv3	RAPv2	HRRRv2
	Jun	RAPv3	RAPv2	HRRRv2
	Jul	RAPv3	RAPv2	HRRRv2
	Aug	RAPv3	RAPv2	HRRRv2
	Sep	RAPv3	RAPv2	HRRRv2
	Oct	RAPv3	RAPv2	HRRRv1
	Nov	RAPv3	RAPv2	HRRRv1
	Dec	RAPv3	RAPv2	HRRRv1
2015	Jan	RAPv3 Update	RAPv2	HRRRv2 Update
	Feb	RAPv3	RAPv2	HRRRv2
	Mar	RAPv3	RAPv2	HRRRv2
	Apr	RAPv3	RAPv2	HRRRv2
	May	RAPv3	RAPv2	HRRRv2
	Jun	RAPv3	RAPv2	HRRRv2
	Jul	RAPv3	RAPv3	HRRRv2
	Aug	RAPv3	RAPv3	HRRRv2
	Sep	RAPv3	RAPv3	HRRRv2
	Oct	RAPv3	RAPv3	HRRRv2
	Nov	RAPv3	RAPv3	HRRRv2
	Dec	RAPv3	RAPv3	HRRRv2

RAPv1: Adoption of GSI, WRF-ARW and unified post processing
Enabled use of community-developed software

RAPv2: Hybrid DA
Significant Improvement in Upper-Air Forecasts

HRRRv1: 3-km Radar DA
Significant Improvement in Convective Forecasts

RAPv3/HRRRv2:
Aerosol Thompson MP, MYNN PBL, RUC LSM, RRTMG Rad, GF Cu
Significant Improvement in Surface Forecasts

Likely RAP version 3 changes

Model	Data Assimilation
<p>WRF-ARWv3.6+</p> <p>Physics changes:</p> <p>Grell-Freitas convective scheme</p> <p>Thompson MP -- Aerosol-aware</p> <p>MYNN PBL -- cloud/non-local mixing</p> <p>RUC LSM -- MODIS seasonal LAI -- improved wilting point</p> <p>Shallow cu parm w/rad feedback</p> <p>RRTMG radiation scheme</p> <p>Direct and diffuse GHI components</p>	<p>Merge with GSI trunk</p> <p>75% global ensemble BEC weight</p> <p>Radiance bias correction, channel selection, RARS data assimilation</p> <p>Radial velocity assimilation</p> <p>Mesonet assimilation</p> <p>Lightning assimilation</p> <p>Pseudo-PBL obs for temperature</p> <p>Improved 2m T, Td diagnostic</p> <p>Low-reflectivity precip building</p>



Experimental RAP/HRRR-2014 Changes

	Model	Data Assimilation
RAP-ESRL (13 km)	<p>WRFv3.5.1+ incl. physics changes</p> <p><u>Physics changes:</u></p> <p>Grell-Freitas convective scheme</p> <p>MYNN PBL update - Olson version</p> <p>RUC LSM update</p> <p>Thompson microphysics – v3.5.1</p> <p>RRTMG radiation scheme</p> <p>Shallow cumulus parm w/ rad feed</p> <p>MODIS veg fraction/leaf area index</p>	<p>Merge with GSI trunk</p> <p>Increase ensemble weight in hybrid DA</p> <p>8m → 2m bkg for sfc Td assim</p> <p>Radiance bias correction</p> <p>New sat assimilation (NOAA-19, METOP-B, GOES, direct readout – RARS)</p>
HRRR (3 km)	<p>WRFv3.5.1+ incl. physics changes</p> <p><u>Physics changes:</u></p> <p>MYNN PBL update - Olson version</p> <p>RUC LSM update</p> <p>Thompson microphysics – v3.5.1</p> <p>RRTMG radiation scheme</p> <p>MODIS veg fraction/leaf area index</p> <p><u>Numerics changes:</u></p> <p>6th order diffusion in flat terrain</p> <p>Smooth terrain @lat BC</p>	<p>3-km hybrid ens/var assimilation (was var-only in 2013)</p> <p>8m → 2m bkg for sfc Td assim</p> <p>Radar LH – 4x less intense than 2013 (2x less intense than RAP but more local)</p> <p>Changes with high/medium importance for <i>overall</i> forecast skill</p>

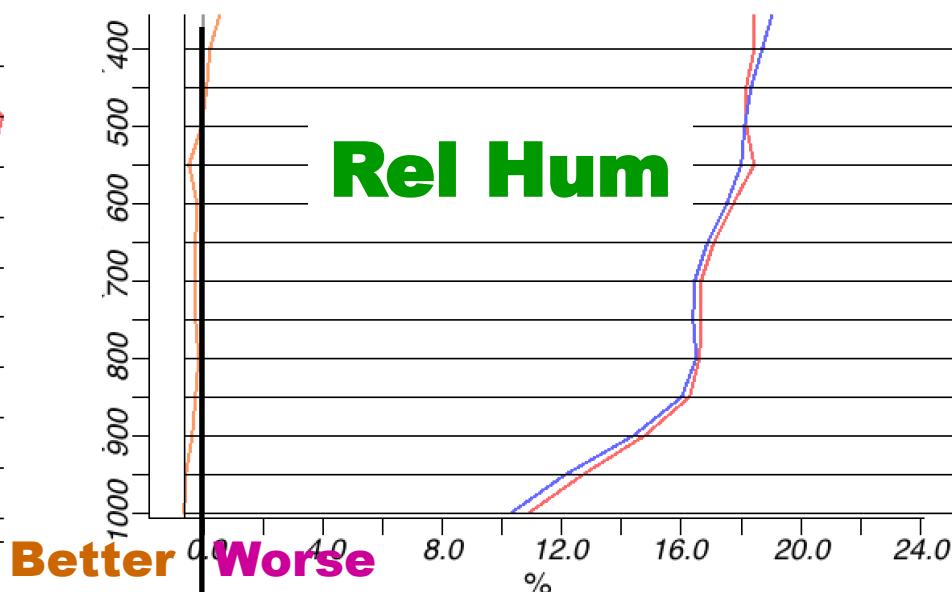
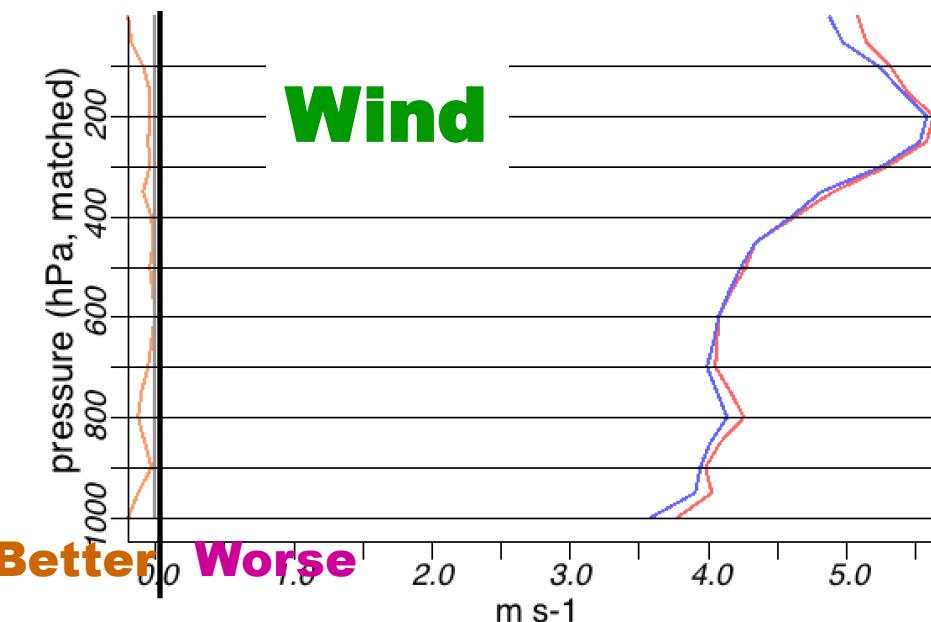


RAPv3: Observations used

Hourly Observation Type	Variables Observed	Observation Count
Rawinsonde	Temperature, Humidity, Wind, Pressure	120
Profiler – NOAA Network	Wind	~10
Profiler – 915 MHz	Wind, Virtual Temperature	20-30
Radar – VAD	Wind	125
Radar	Radial Velocity	125 radars
Radar reflectivity – CONUS	Rain, Snow, Hail	1,500,000
Lightning	(proxy reflectivity)	NLDN
Aircraft	Wind, Temperature	2,000 -15,000
Aircraft - WVSS	Humidity	0 - 800
Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2200 - 2500
Surface/Mesonet	Temperature, Moisture, Wind	~5000
Buoys/ships	Wind, Pressure	200 - 400
GOES AMVs	Wind	2000 - 4000
AMSU/HIRS/MHS	Radiances	5,000
GOES cloud-top press/temp	Cloud Top Height	100,000
GPS – Precipitable water	Humidity	260
WindSat Scatterometer	Winds	2,000 – 10,000



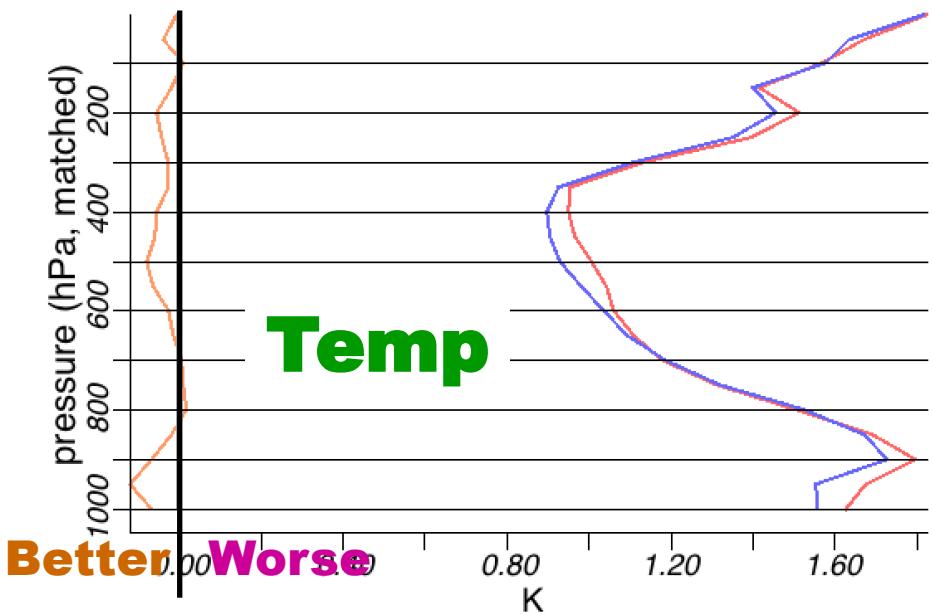
R/T Upper-air: RAPv3 vs. oper RAPv2



upper-air verification

+ 12 h forecast
RMS Error

15 Sept – 1 Dec 2014

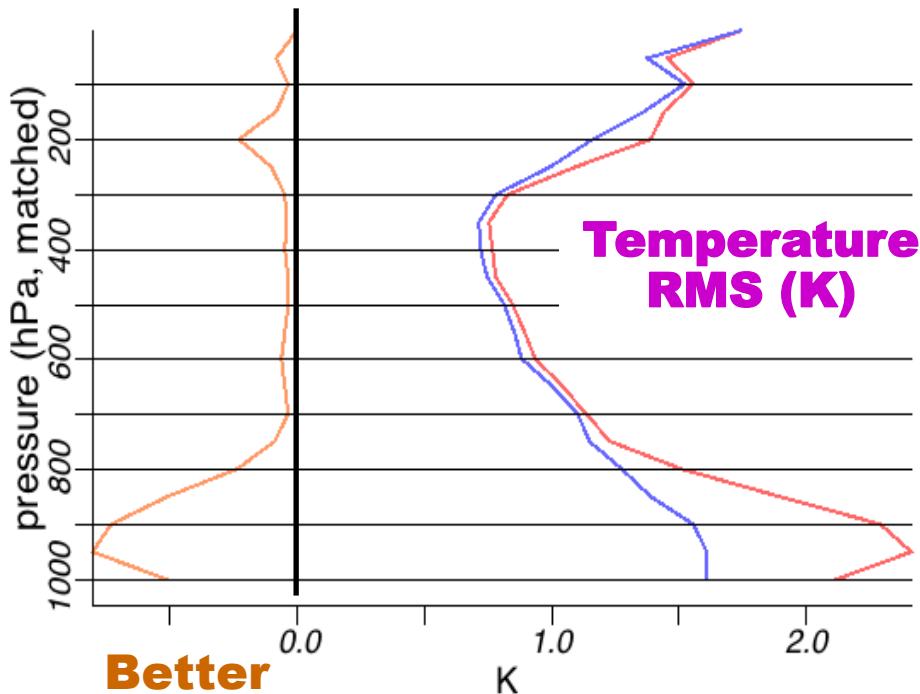
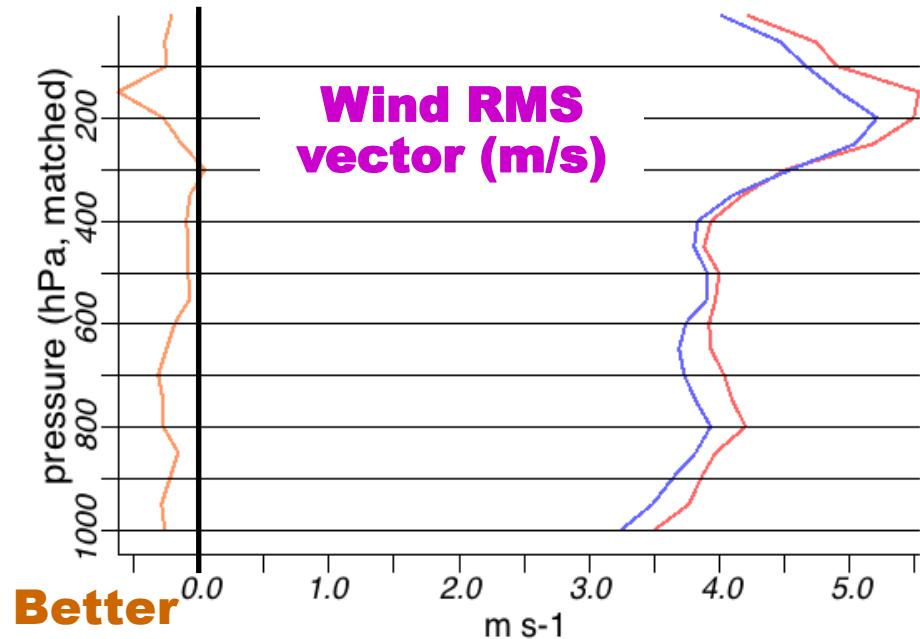
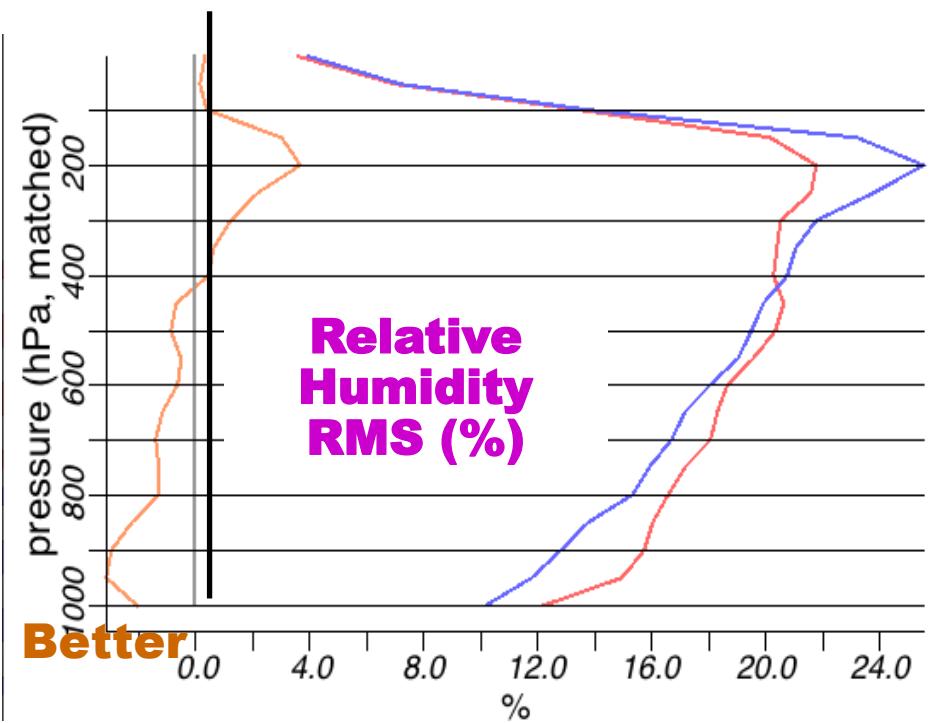


Rapid Refresh

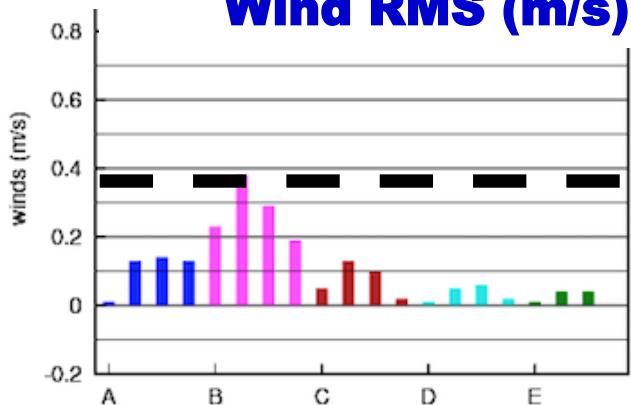
12h Upper-air verification (summer retrospective)

NCEP OPER RAPv2
GSD RAPv3 pre-NCEP

CONUS Vs. raobs
16-28 July 2014

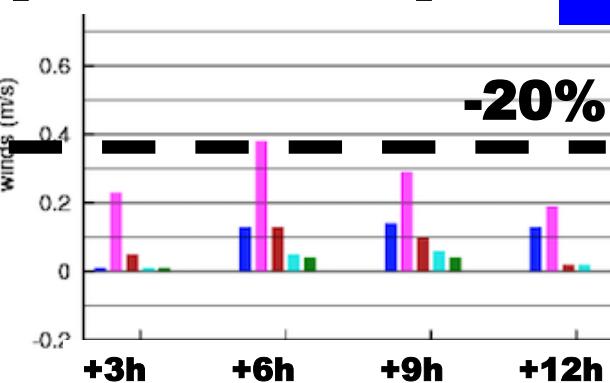


Wind RMS (m/s) [1000-1000 hPa]

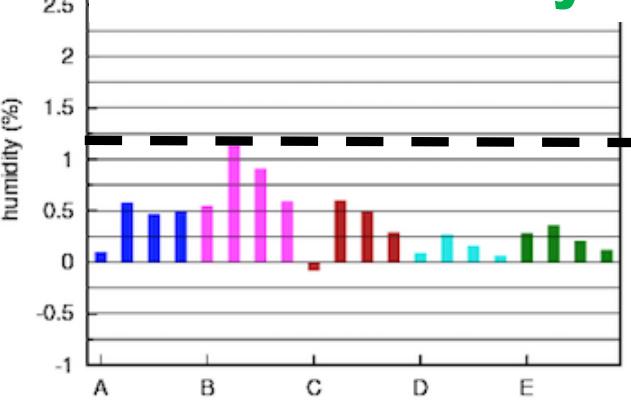


RAP 2013 obs impact

-20%



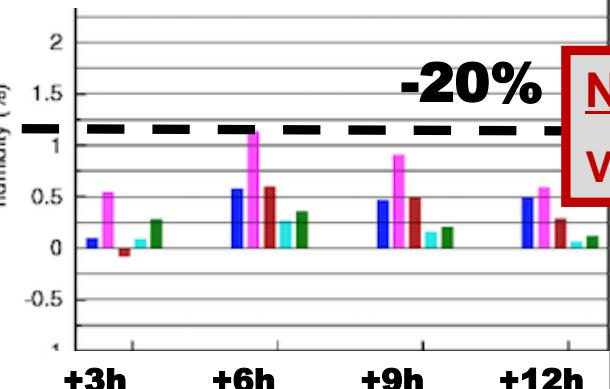
Relative Humidity RMS (%) [1000-400 hPa]



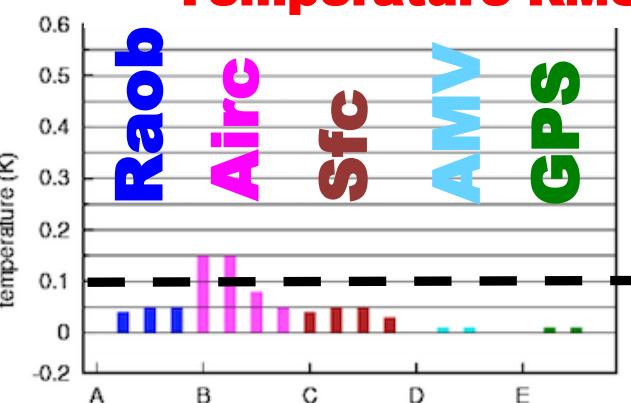
Normalize: 6h Fcst – 0h Anx

V – 1.8 m/s, RH – 6%, T – 0.5K

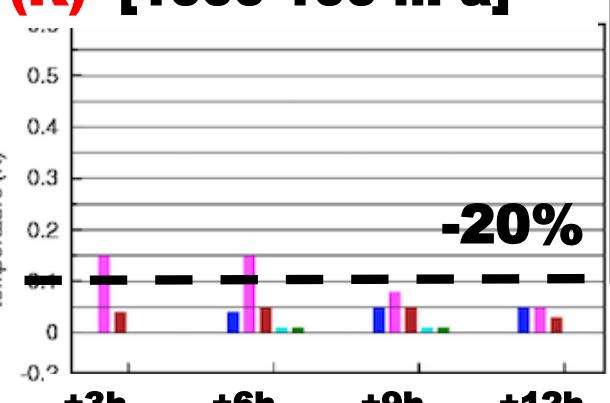
-20%



Temperature RMS (K) [1000-100 hPa]



-20%



Aircraft – largest impact

wind/RH/temp – all have up to 20% reduction forecast error, especially 6h-9h fcsts

Following in importance:

**Raob, Surface,
GPS-Met, AMVs**



NCEP RAPv2 and HRRR 2014

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D- VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time- Step
RAP	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20 s



NCEP RAPv3 and HRRRv2 2015

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6.1+	GSI Hybrid 3D- VAR/Ensemble	13-km DFI	RRTMG/ RRTMG	Thompson – aerosol-aware v3.6.1	GF – v3.6.1	MYNN v3.6.1+	RUC 9-lev v3.6.1+
HRRR	WRF-ARW V3.6.1+	GSI 3D- VAR/Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson – Aerosol-aware v3.6.1	None	MYNN	RUC 9-lev v3.6.1+

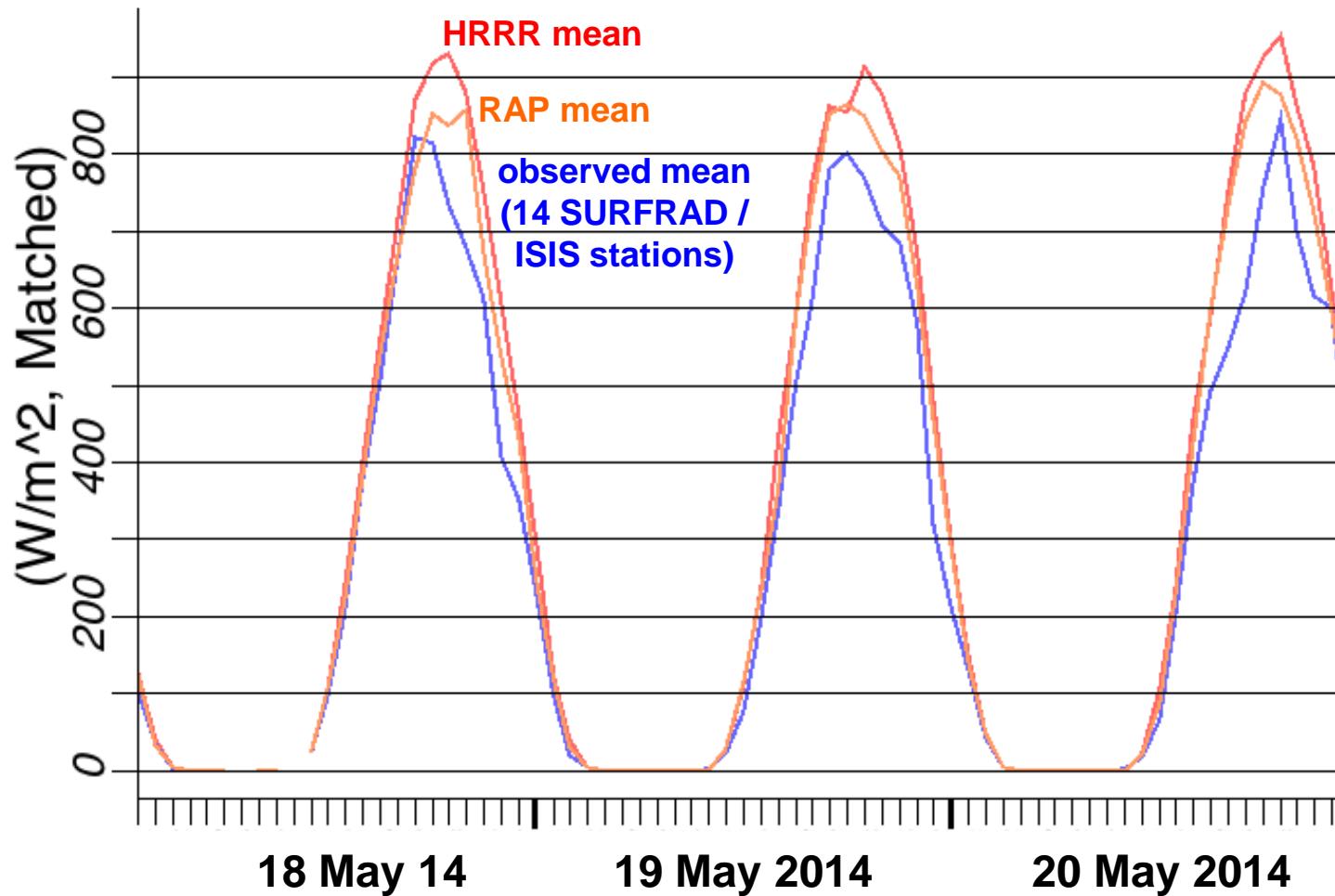
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time- Step
RAP	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5 th /5 th	Positive- Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW- dt (Ruiz-Arias)	MODIS Fractional	0.07 K/s	20 s



Cloud Deficiency in RAP and HRRR

A problem for convection/ceiling/terminal forecasts

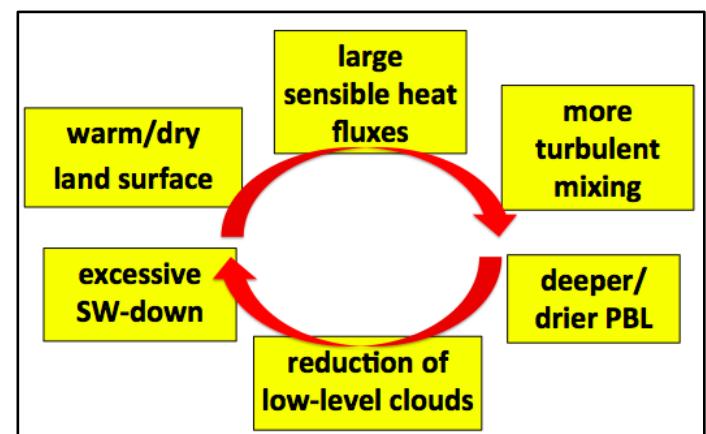
12-h forecasts of downward shortwave flux at surface





Physics updates to reduce warm / dry bias

- **Grell–Freitas “scale-aware” shallow cumulus (subgrid-scale)**
 - Accounts for **nonlocal** mixing of heat & water vapor from condensed (non-precipitating) subgrid plumes
 - “Scale-aware” mass flux scheme
 - Produces **subgrid** cloud water & ice
 - ➔ **coupled to radiation**
- **MYNN boundary-layer cloud fraction (subgrid-scale)**
 - Function of local and PBL-mean RH, surface heat flux, resolution
 - Activates in absence of resolved / parameterized cloud fraction in column
 - Diagnoses **subgrid** cloud water & ice
 - (specifically for radiation coupling)**
- **RUC-LSM**
 - **Reduced wilting points**
 - **Maintain cropland at wilting point**





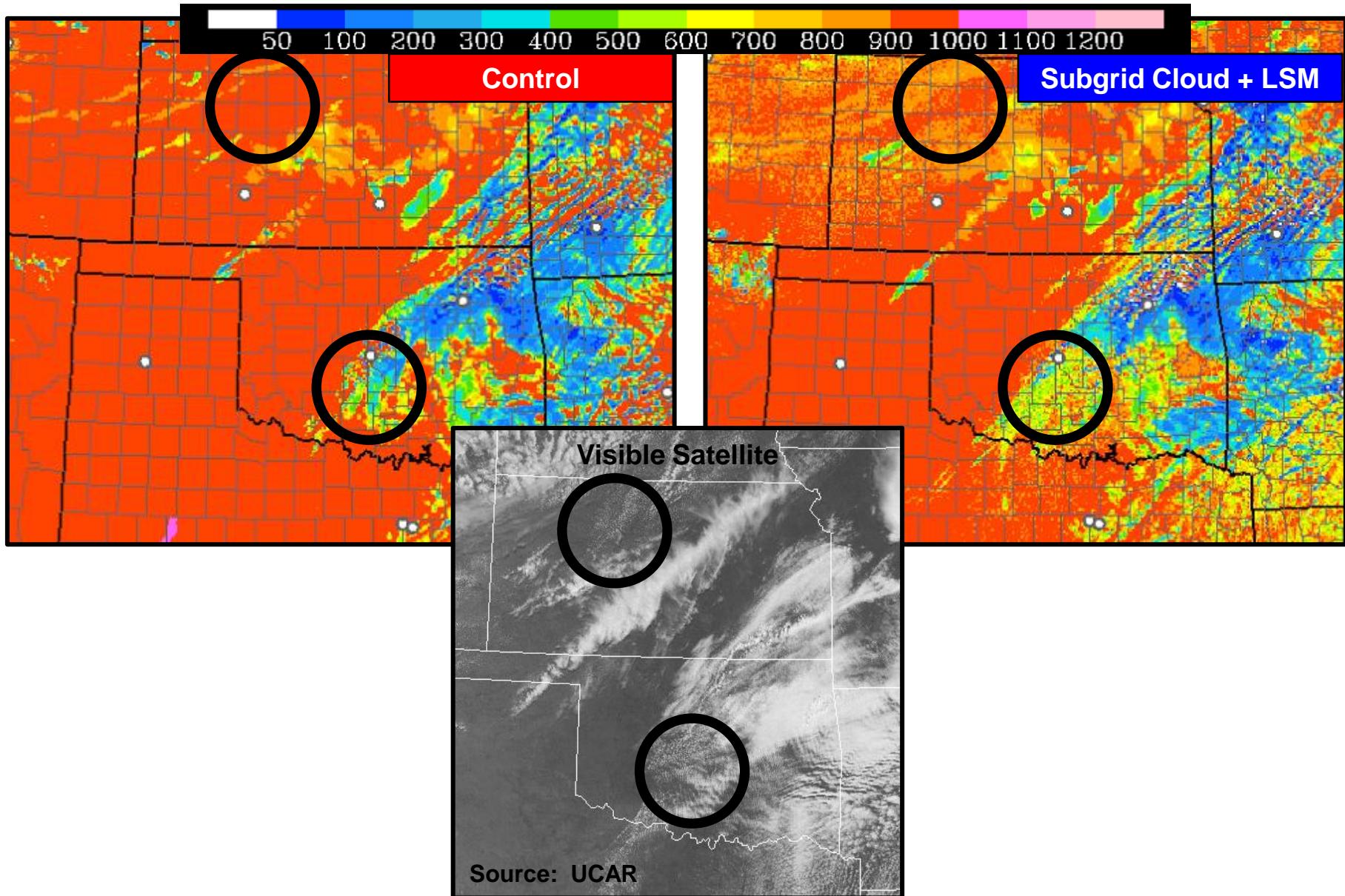
RAP/HRRR Warm/Dry Bias Mitigation

Component	Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point



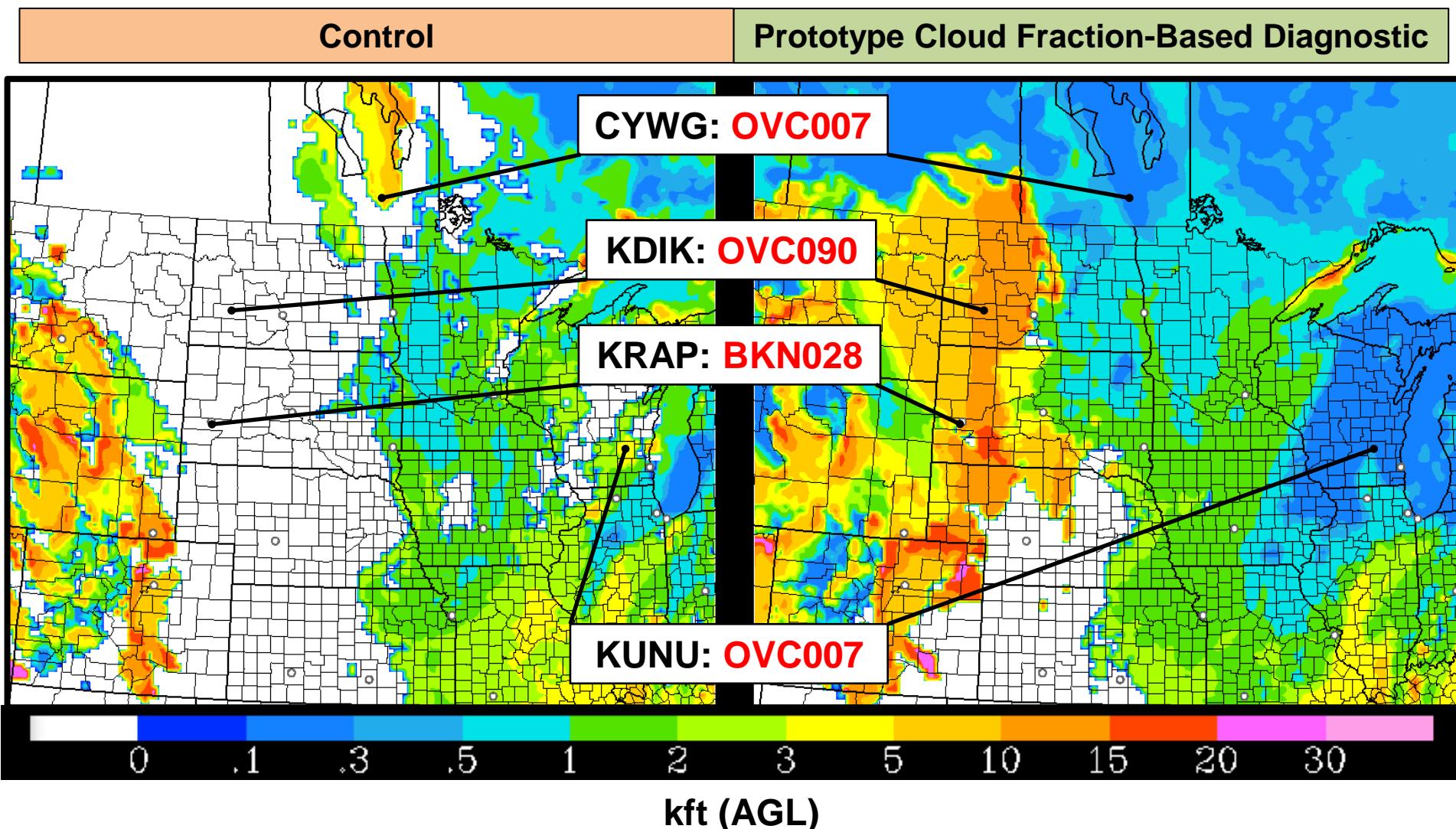
Results: HRRR Downward SW Flux at Surface

8-h forecasts valid 1700 UTC 20 May (W m^{-2})



Example: 30 January 2013

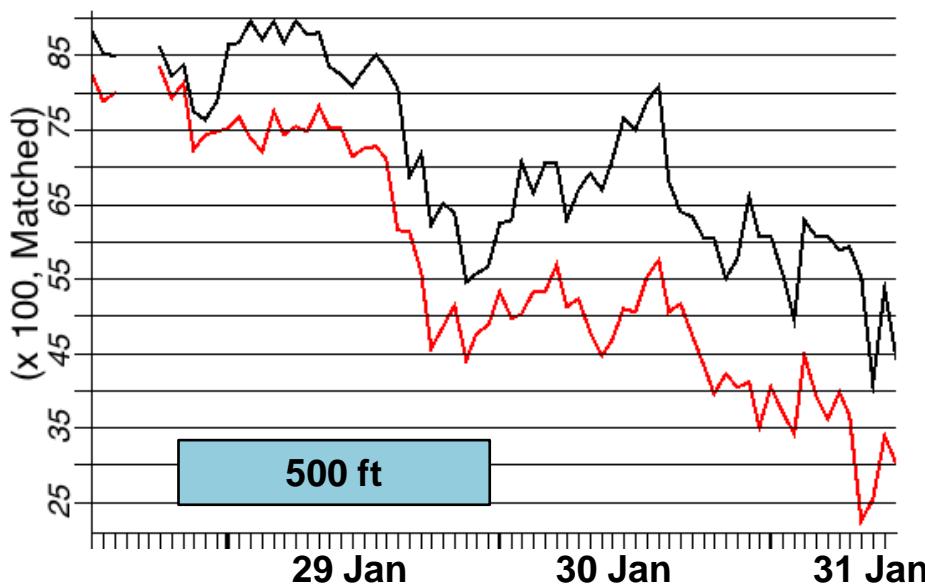
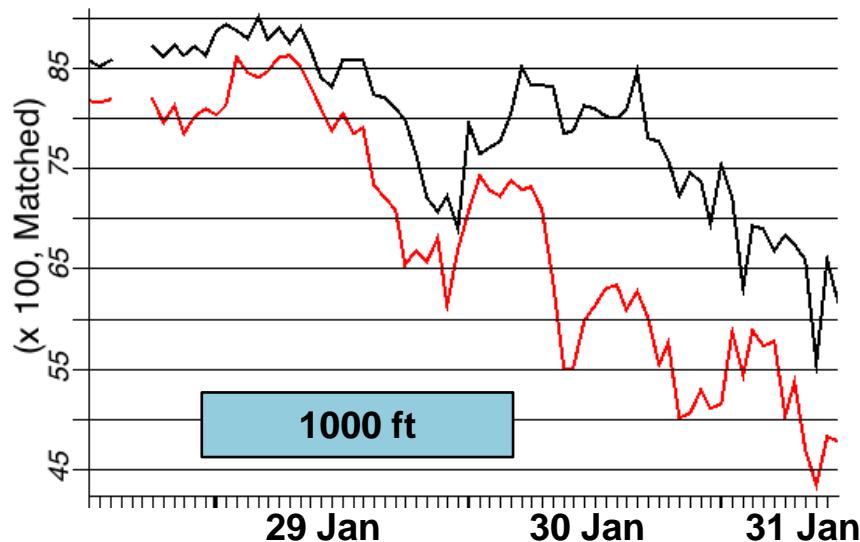
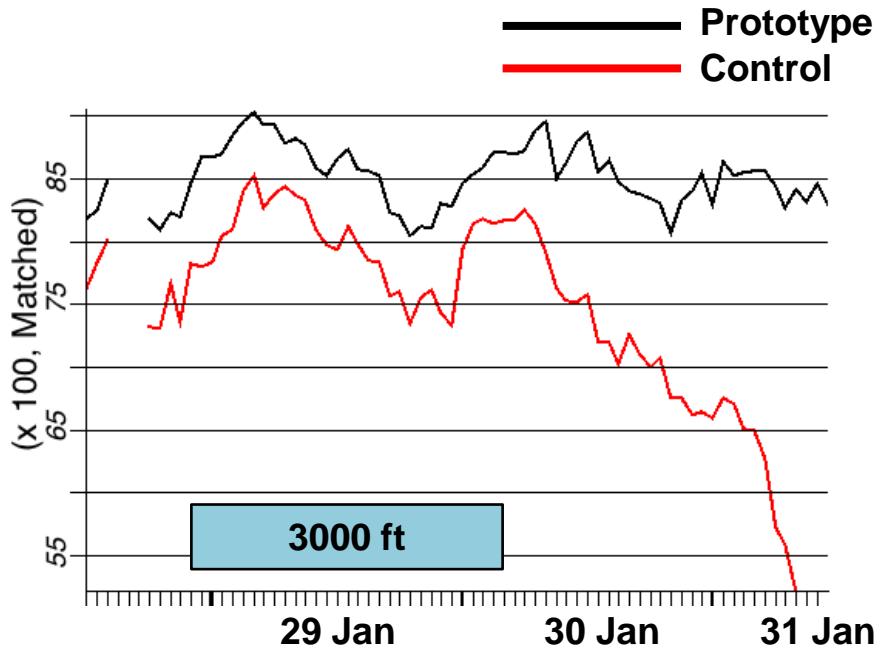
selected ceiling reports versus 12-h ceiling forecasts (valid 2000 UTC)





Ceiling – new cloud-fraction diagnostic for RAP/HRRR

Results: Probability of Detection (12-h forecasts, CONUS)





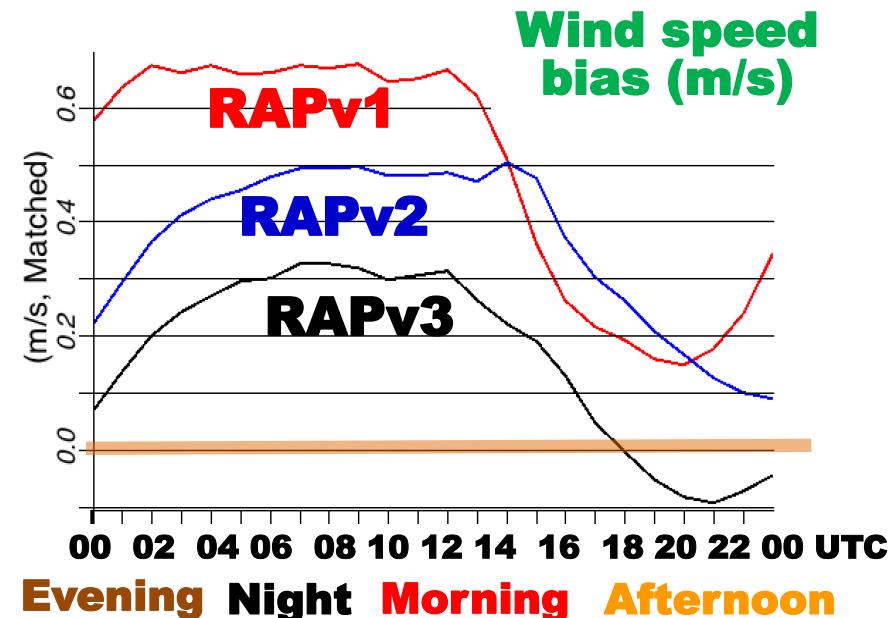
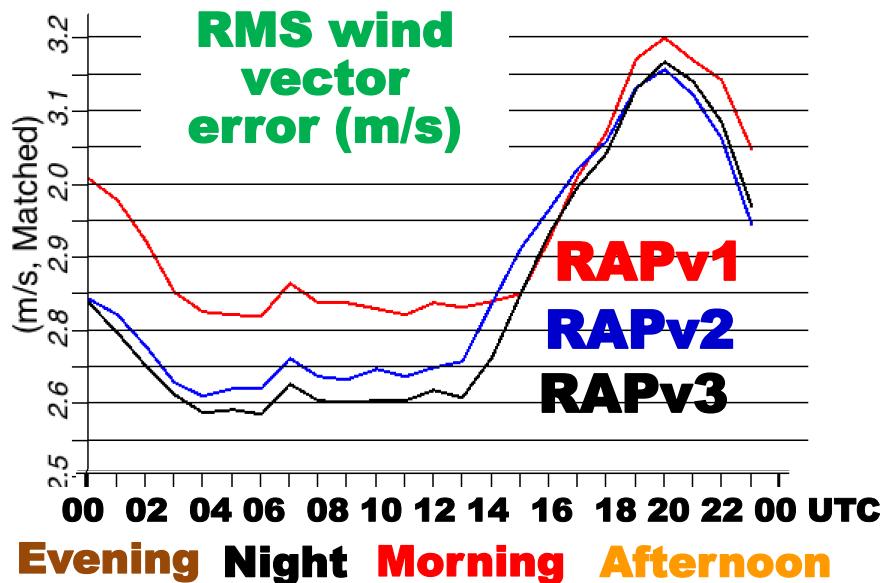
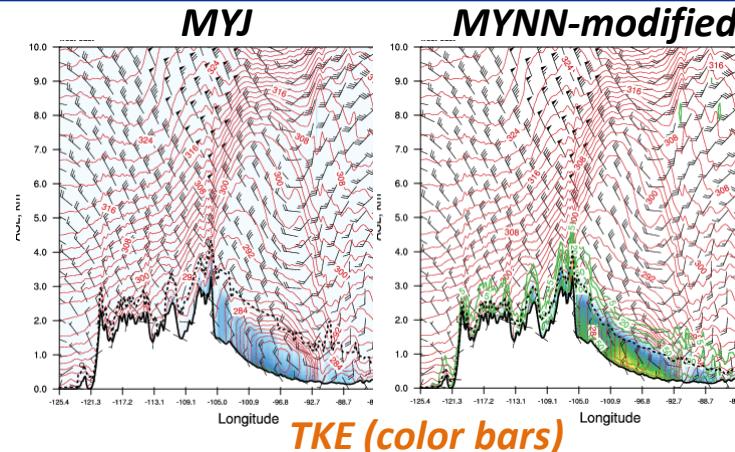
RAP / HRRR use of MYNN PBL scheme

First implemented with RAPv2 / HRRR 2013 –
better convection, wind forecasts

Improved mixing length formulations to
flexibly change behavior across the stability spectrum

Improved surface layer scheme (customization to PBL)

Further enhancements for RAP v3 / HRRR v2 -- cloud mixing,
refined closure constants, coupling to different shallow cu schemes

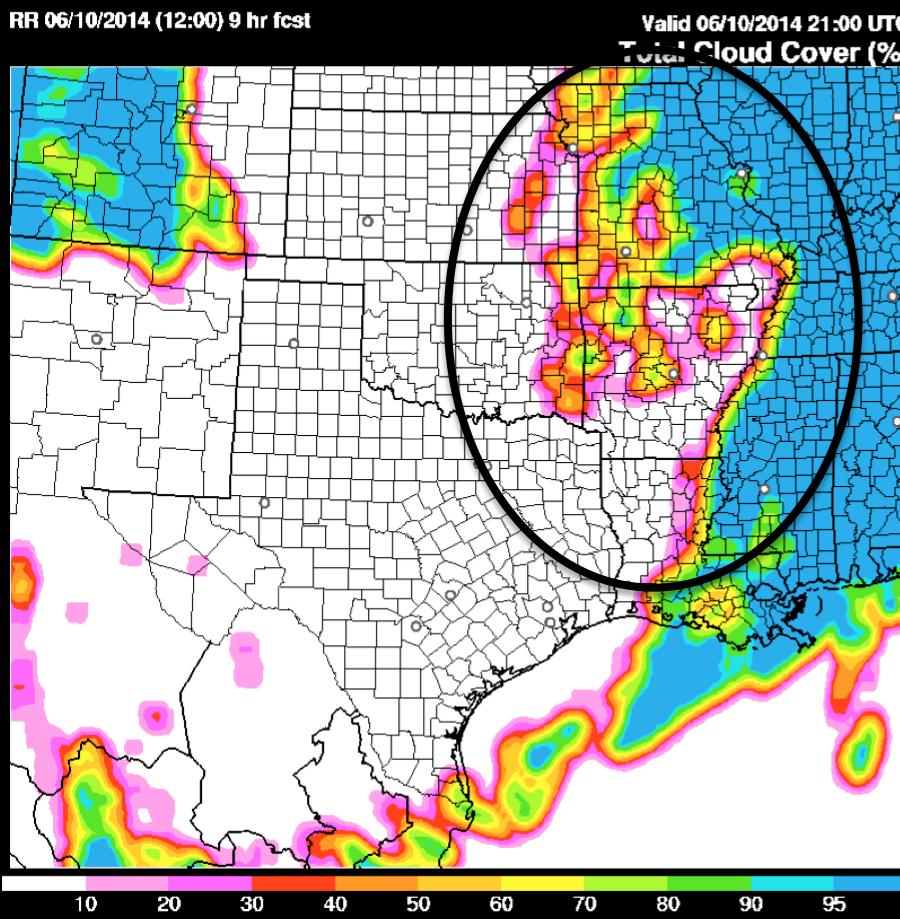




NCEP RAPv3/HRRRv2-2015 Changes

Use of forecast aerosol fields
to have prognostic cloud-
condensation nuclei (CCN).

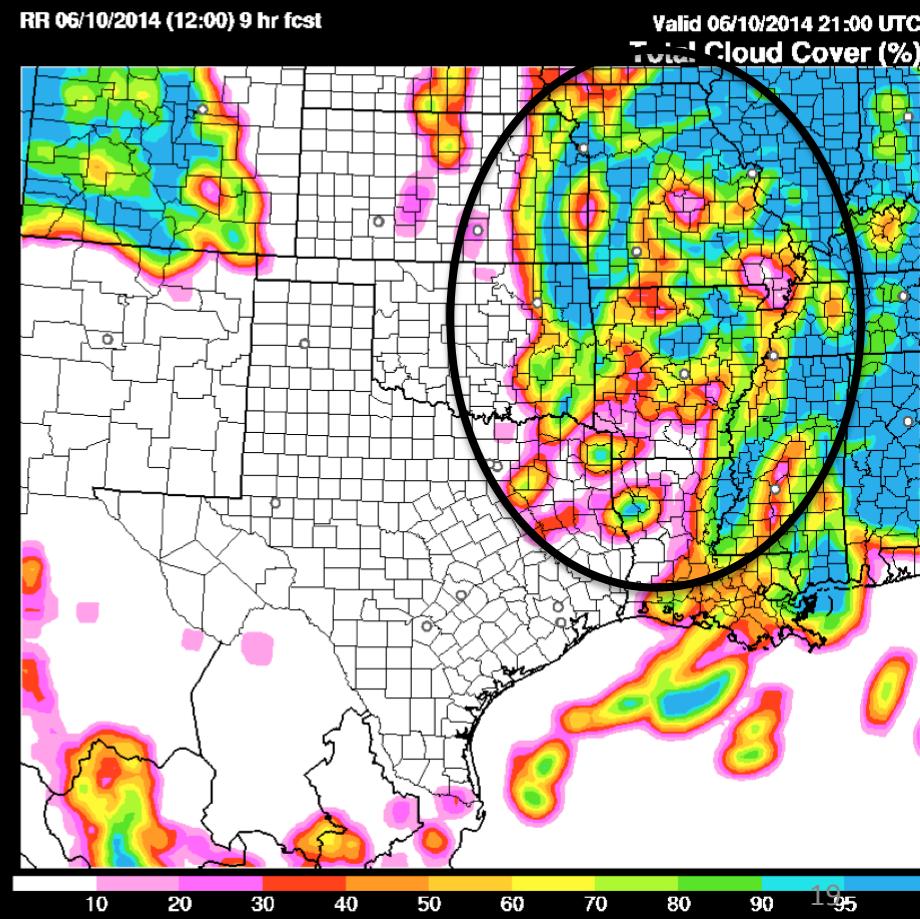
WRFv3.5.1 aerosol unaware



Example: RAP cold-start tests without/with aerosol-aware cloud microphysics.

More small-scale clouds with more CCN over land.

WRFv3.6 Aerosol-aware



Aviation Flight Rules (ceiling and visibility)

RAPv3

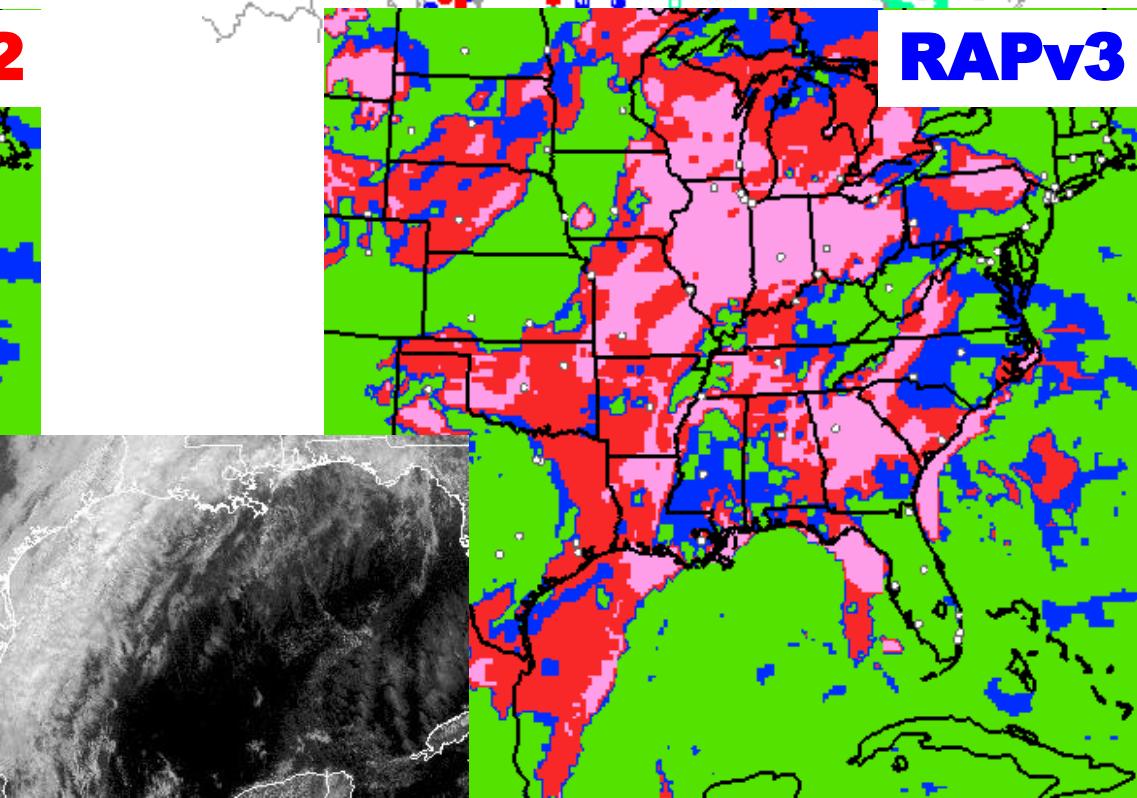
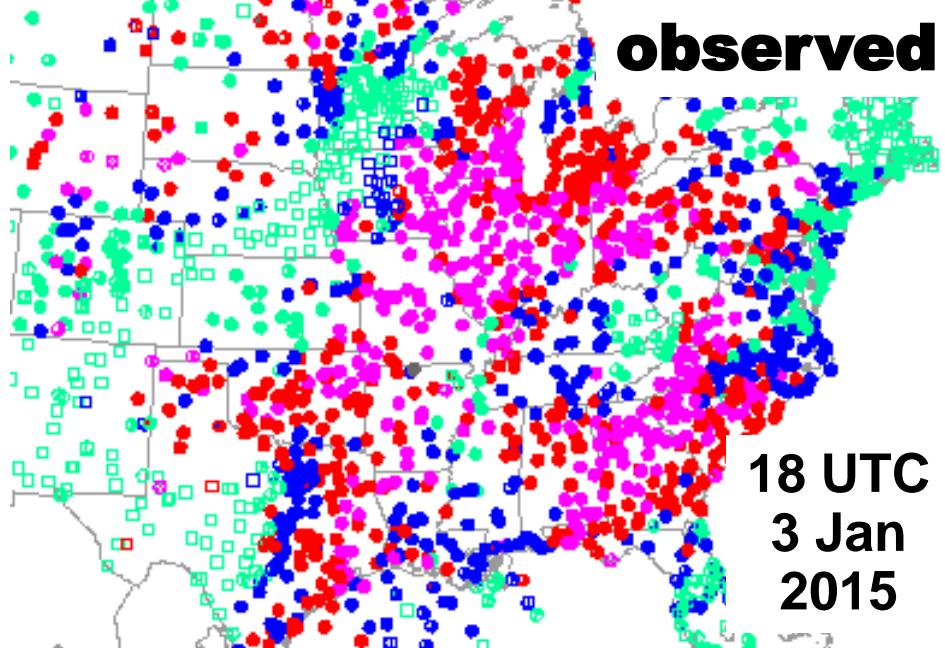
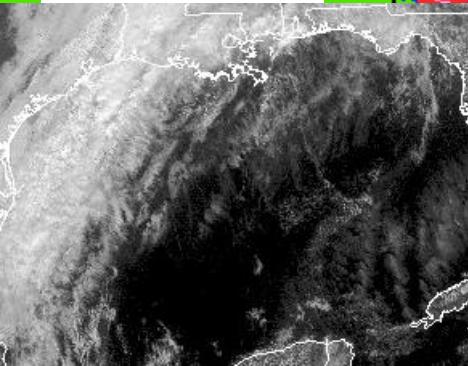
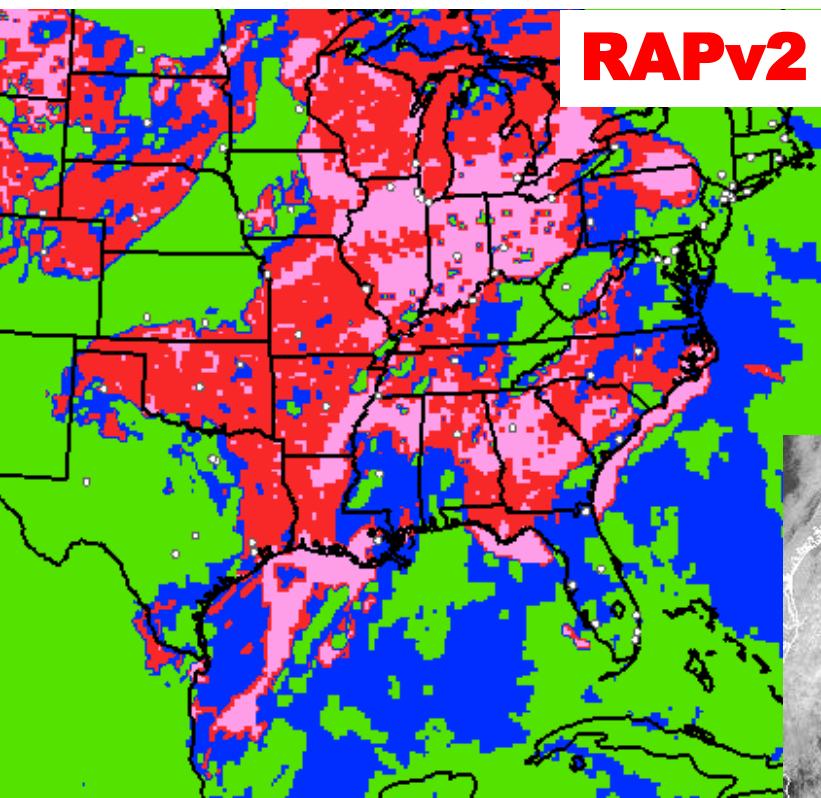
3 Jan 2015

vs.

RAPv2

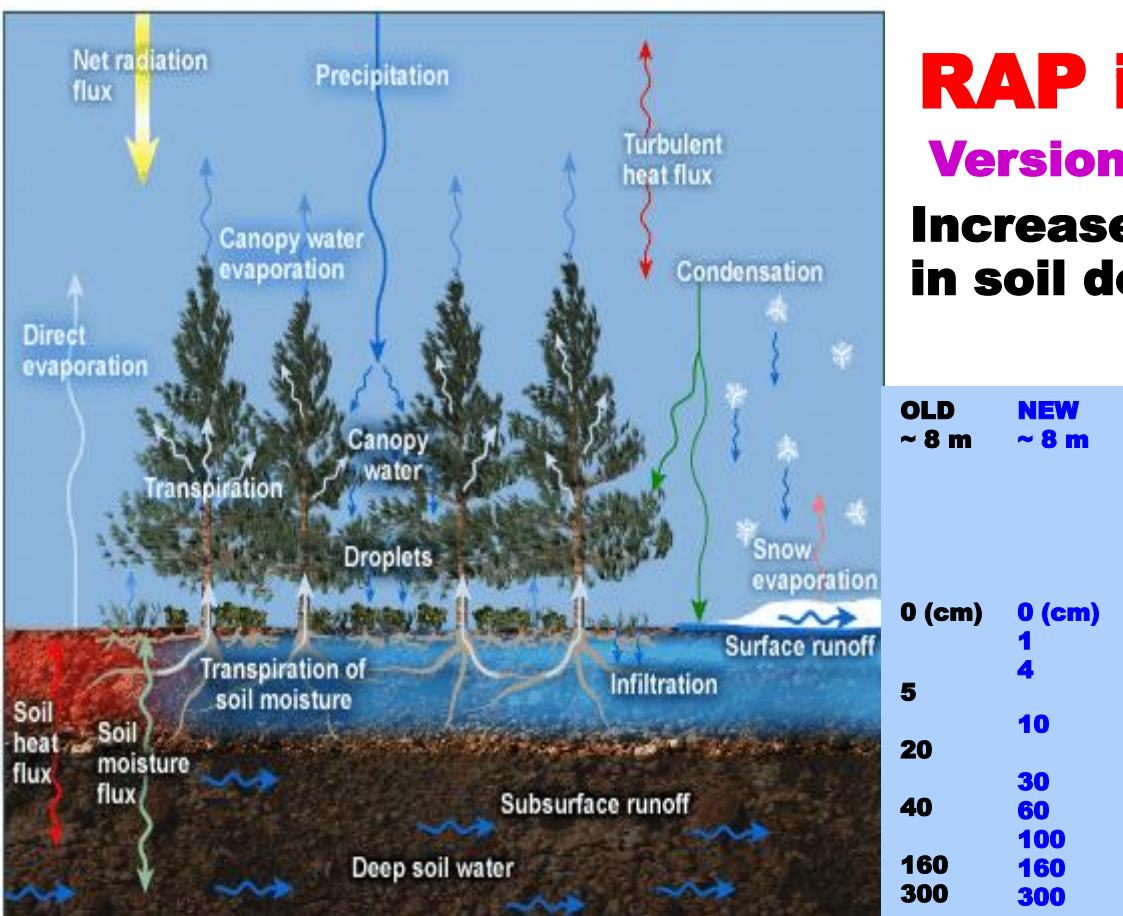
6 UTC

+ 12h fcst





Updates to RUC Land Surface Model



Thinner soil layer in energy / moisture budgets
 Potential for increased near-surface diurnal cycle
 Reduced warm bias at night, cold bias in day

RAP improvements

Version 2

Increased number of levels in soil domain – 9 levels

- Increased roughness Z_0 for forests, cropland, urban
- New formulation to compute effective roughness length $Z_{0\text{eff}}$ in the grid box (exponential)

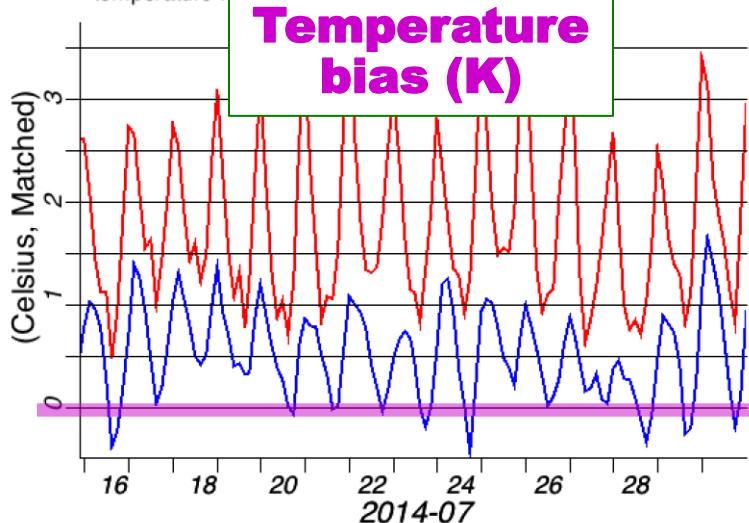
Version 3 (partial list)

- Seasonal variations of Z_0 for MODIS cropland category
- Seasonal variations of LAI based on the current vegetation fraction and variability of this parameter for different vegetation types

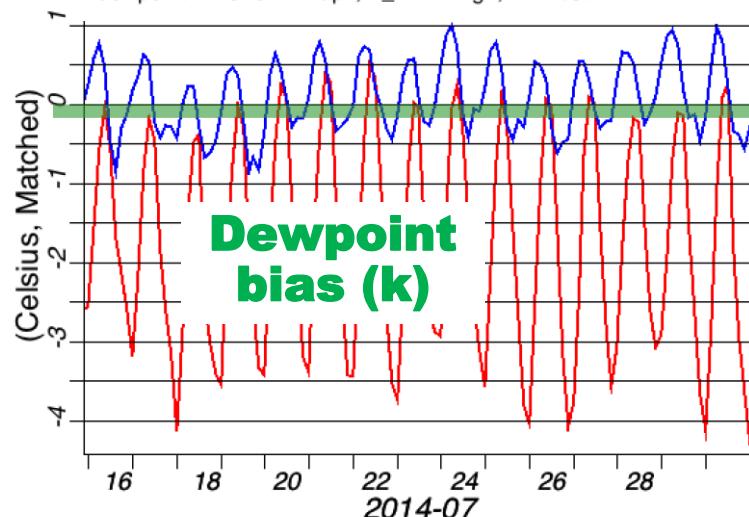
Overall: Rapid Refresh 12h Surface verification

NCEP OPER RAPv2
GSD RAPv3 pre-NCEP

- temperature FmO for RRret_protoRAPv3_summer, E_HRRR rgn, 12h fcst
- temperature FmO for RRrapx, E_HRRR rgn, 12h fcst

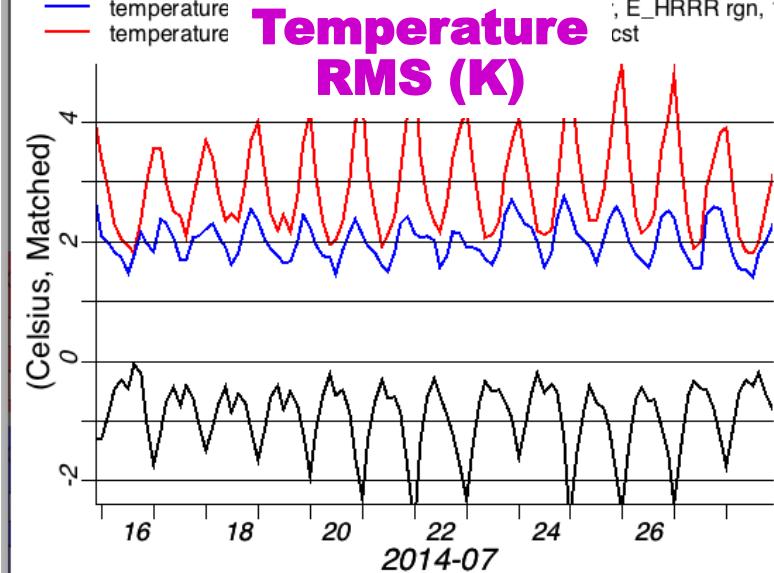


- dewpoint FmO for RRret_protoRAPv3_summer, E_HRRR rgn, 12h fcst
- dewpoint FmO for RRrapx, E_HRRR rgn, 12h fcst

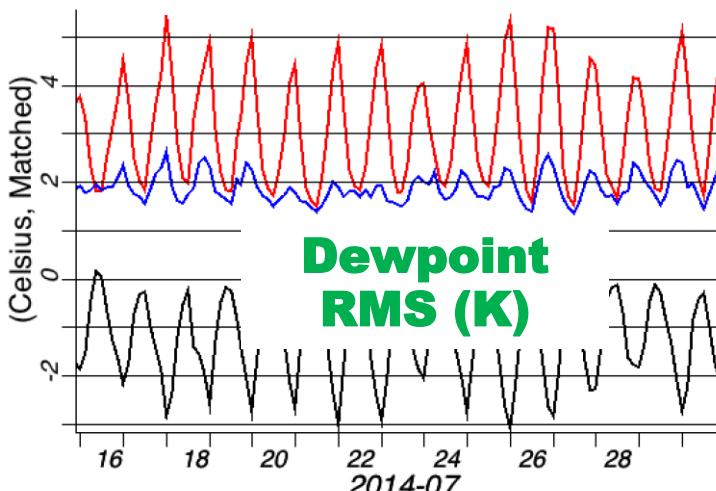


Warm Cold Moist Dry

- temperature RMS for RRret_protoRAPv3_summer-RRrapx, E_HRRR rgn, 12h fcst
- temperature RMS for RRret_protoRAPv3_summer, E_HRRR rgn, 12h fcst



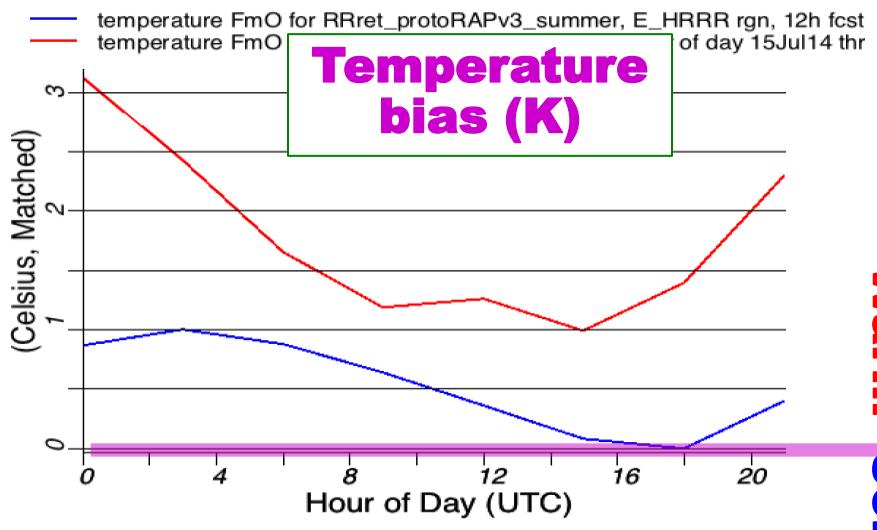
- dewpoint RMS for RRret_protoRAPv3_summer-RRrapx, E_HRRR rgn, 12h fcst
- dewpoint RMS for RRret_protoRAPv3_summer, E_HRRR rgn, 12h fcst
- dewpoint RMS for RRrapx, E_HRRR rgn, 12h fcst



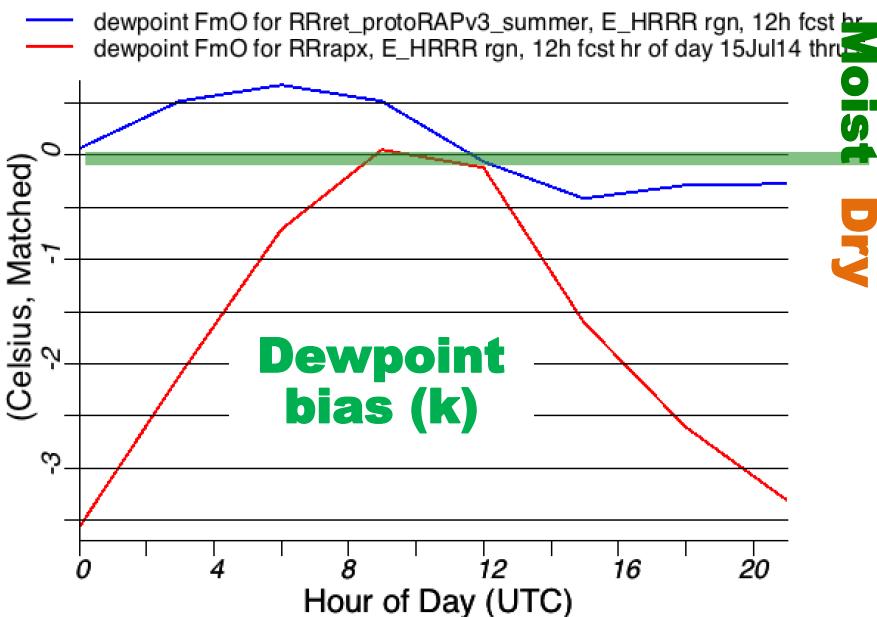
East US
15-30
July
2014
22

Overall: Rapid Refresh 12h Surface verification

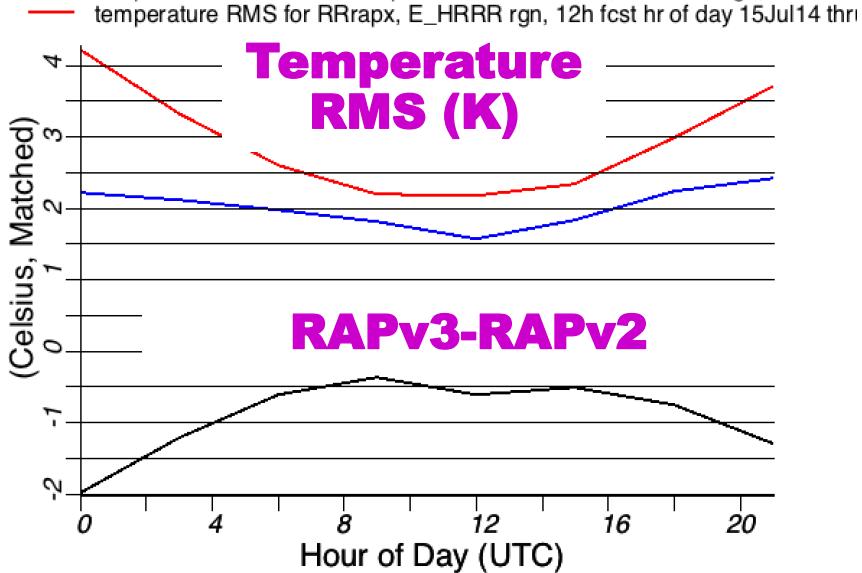
NCEP OPER RAPv2
GSD RAPv3 pre-NCEP



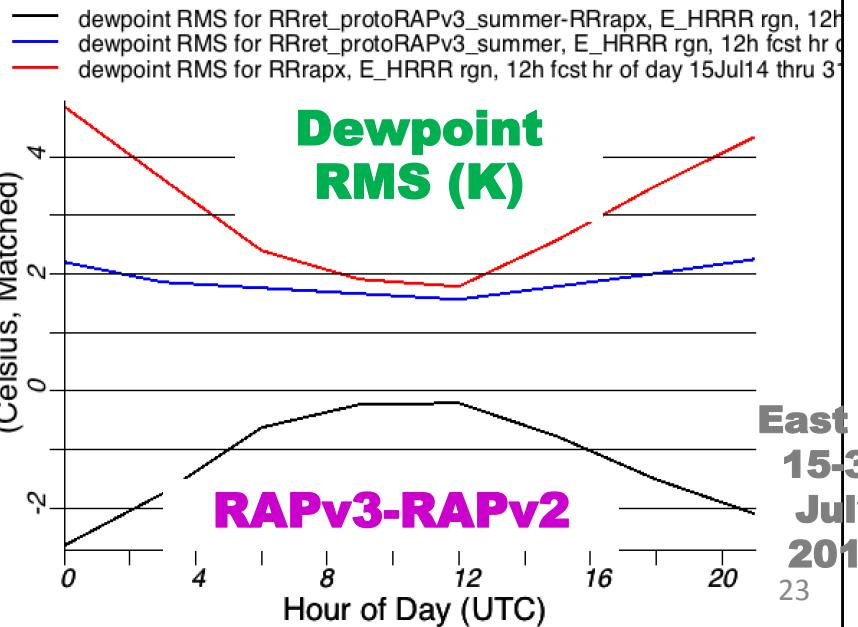
Warm
Cold



Moist
Dry



RAPv3-RAPv2



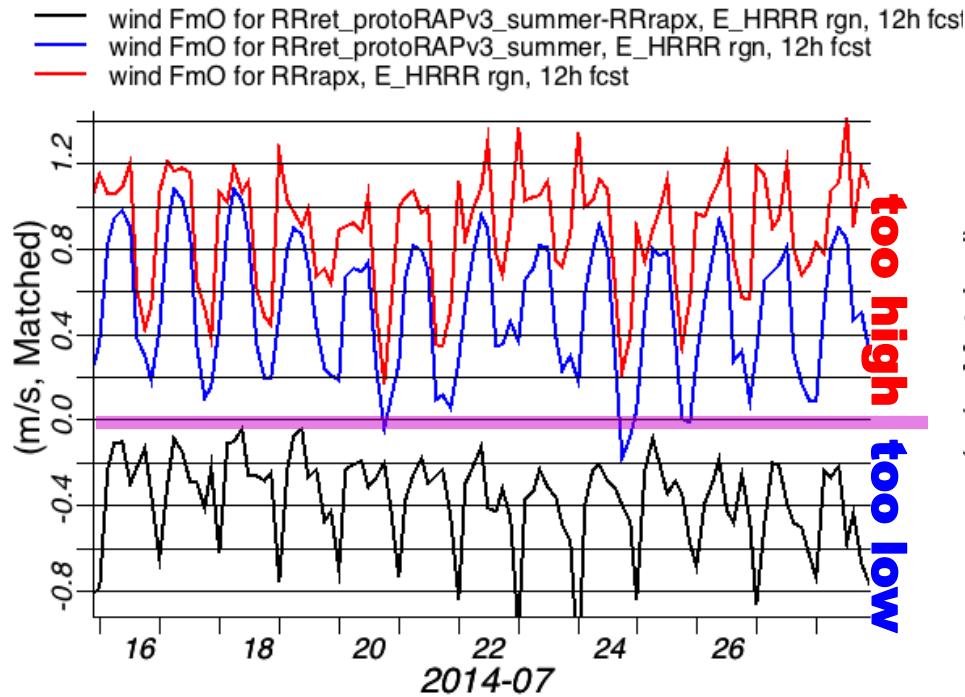
Dewpoint
RMS (K)

RAPv3-RAPv2

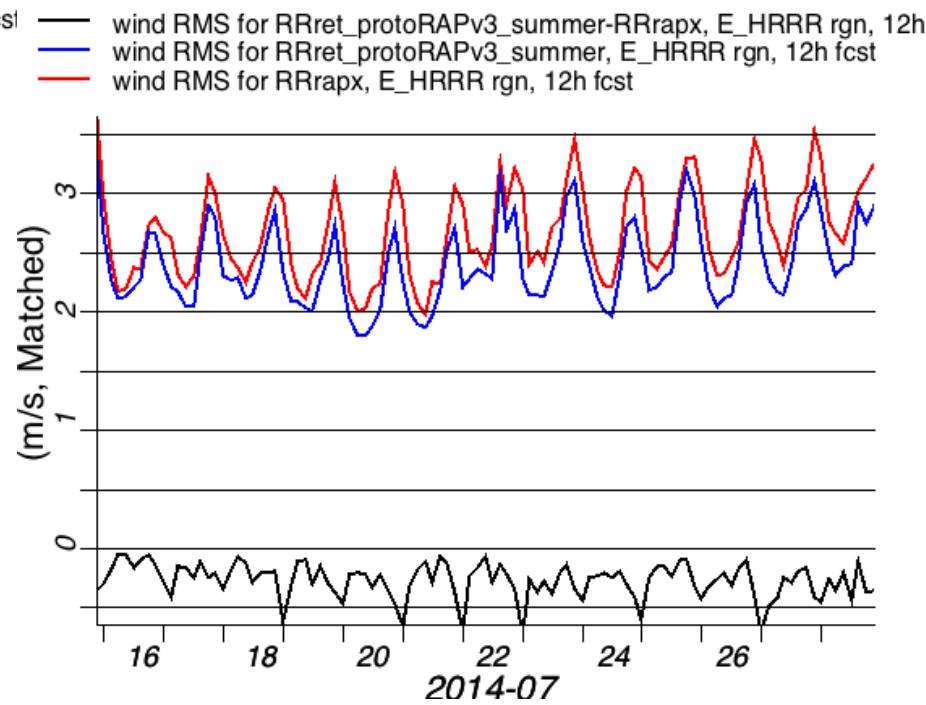
East US
15-31
July
2014
23

Overall: Rapid Refresh 12h Surface verification

NCEP OPER RAPv2
GSD RAPv3 pre-NCEP



10m Wind
bias (m/s)



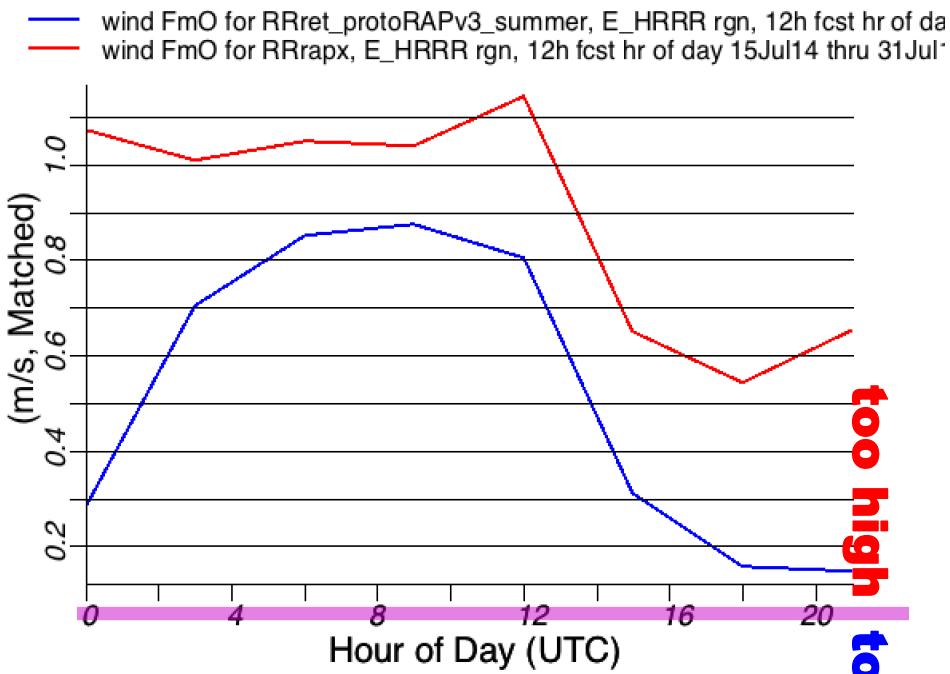
10m wind
RMS vector
error (m/s)

East US
15-30
July
2014

Overall: Rapid Refresh

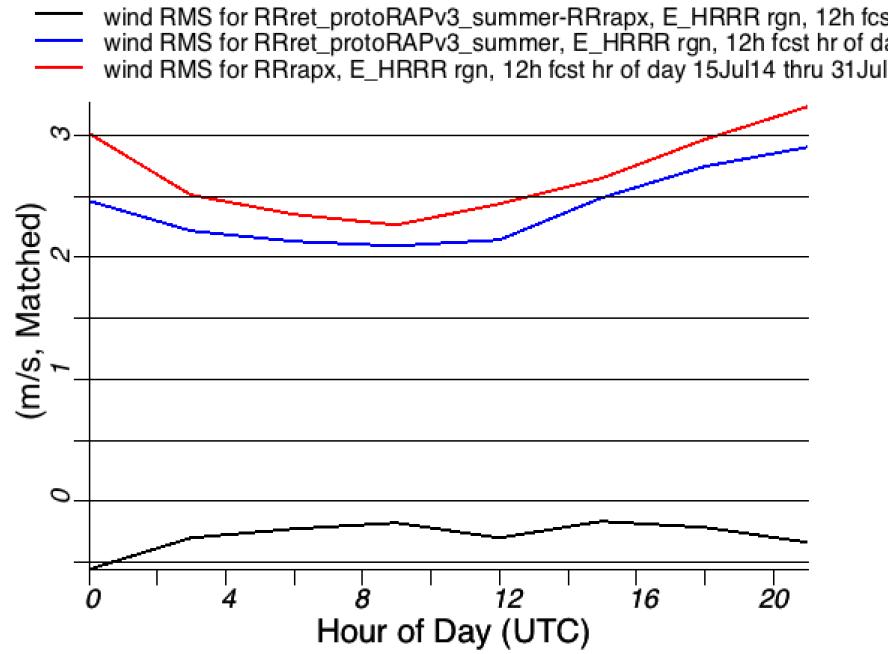
12h fcst – 10m wind verification

NCEP OPER RAPv2
GSD RAPv3 pre-NCEP



DIURNAL Variation
10m Wind bias (m/s)

too high
too low

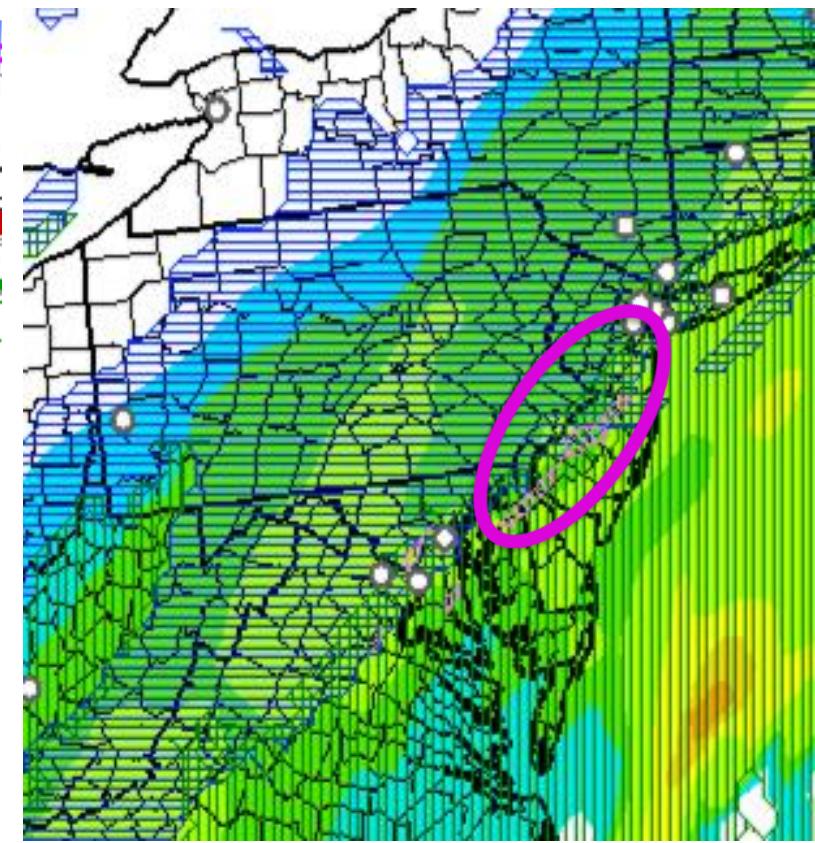
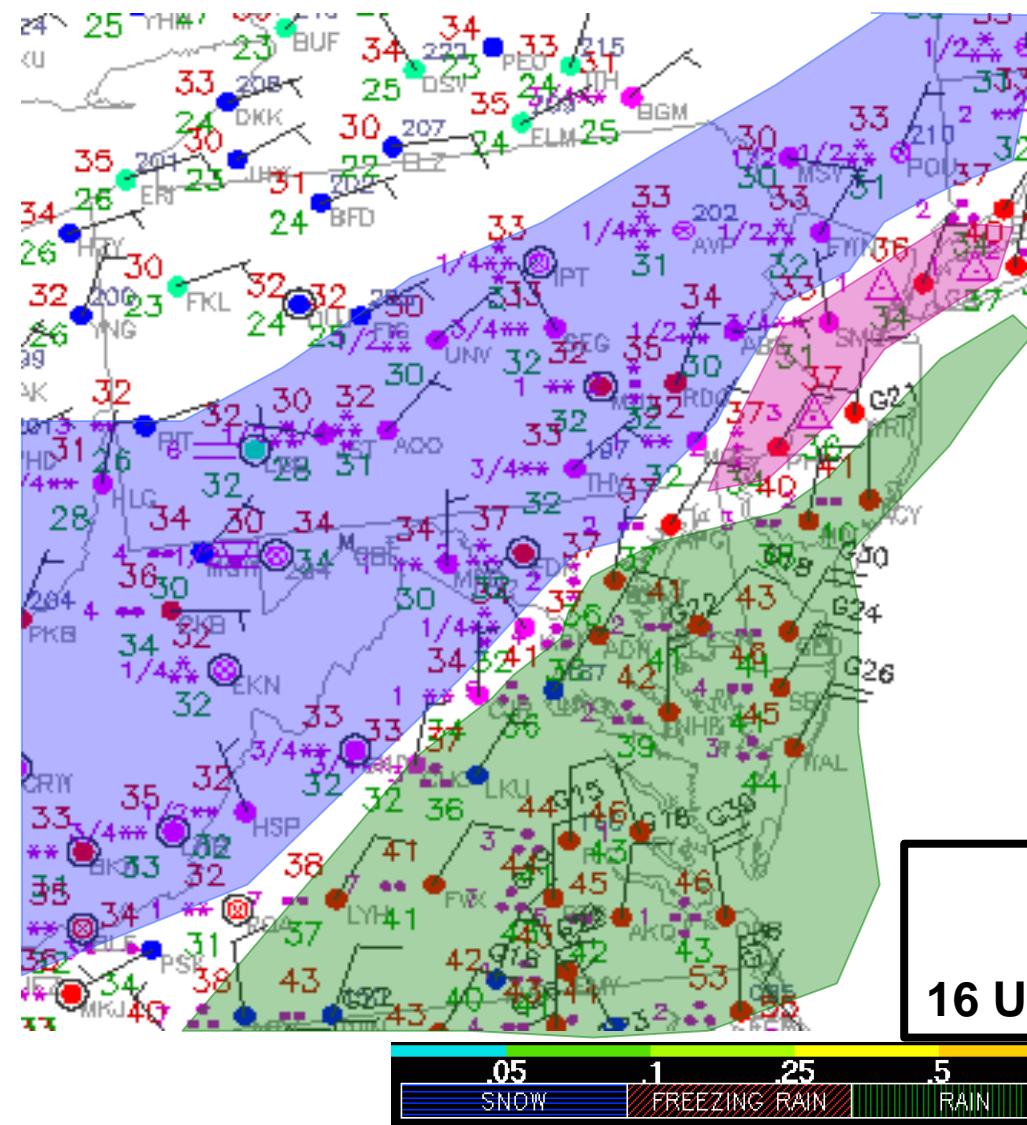


DIURNAL Variation
10m wind RMS vector
error (m/s)

East US
15-31
July
2014



Improved RAP Precip Type

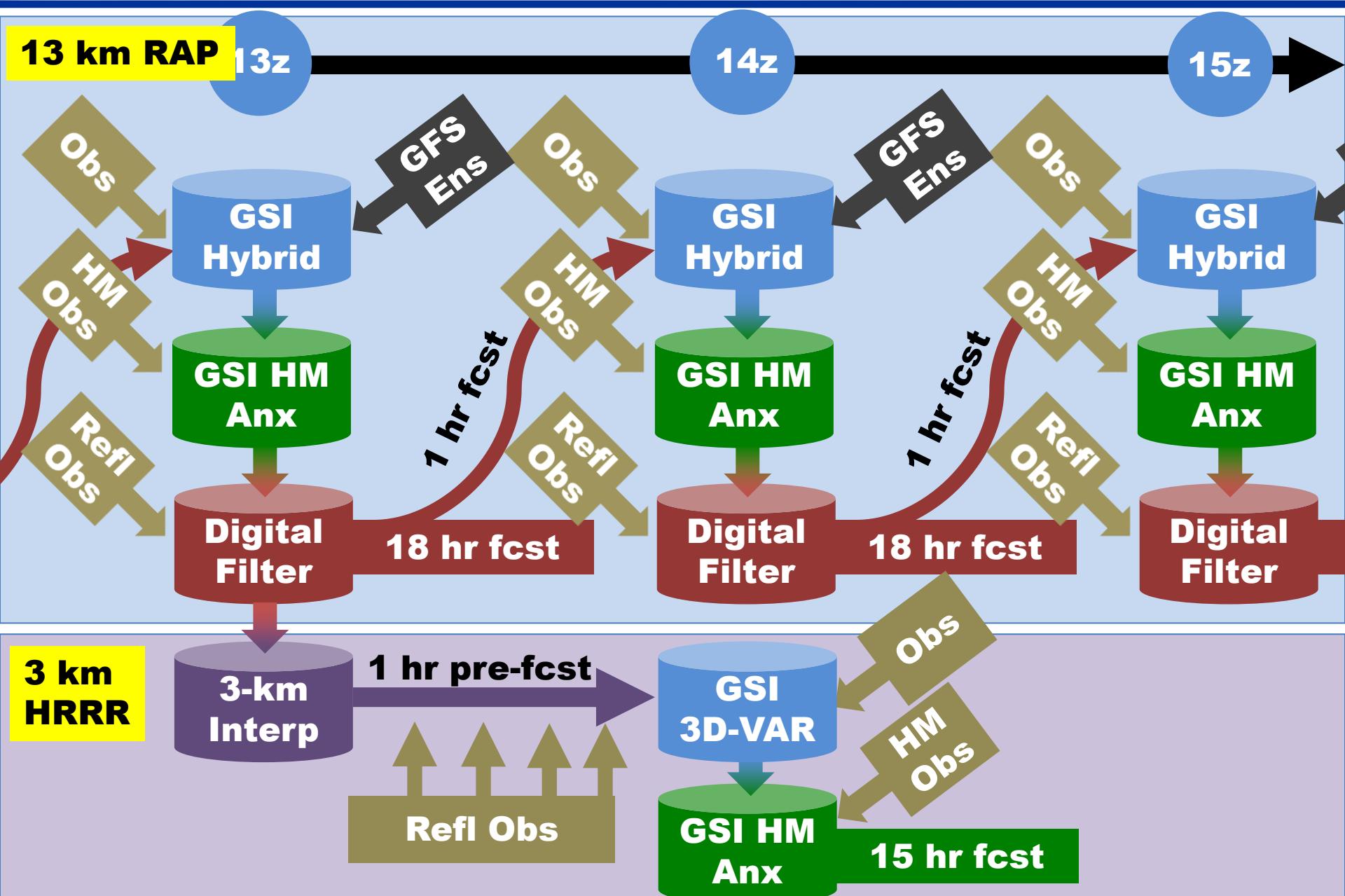


RAPX
18 hr Fcst
16 UTC 26 Nov 2014

**RAP resolves
narrow IP band
(improved
diagnostic)**

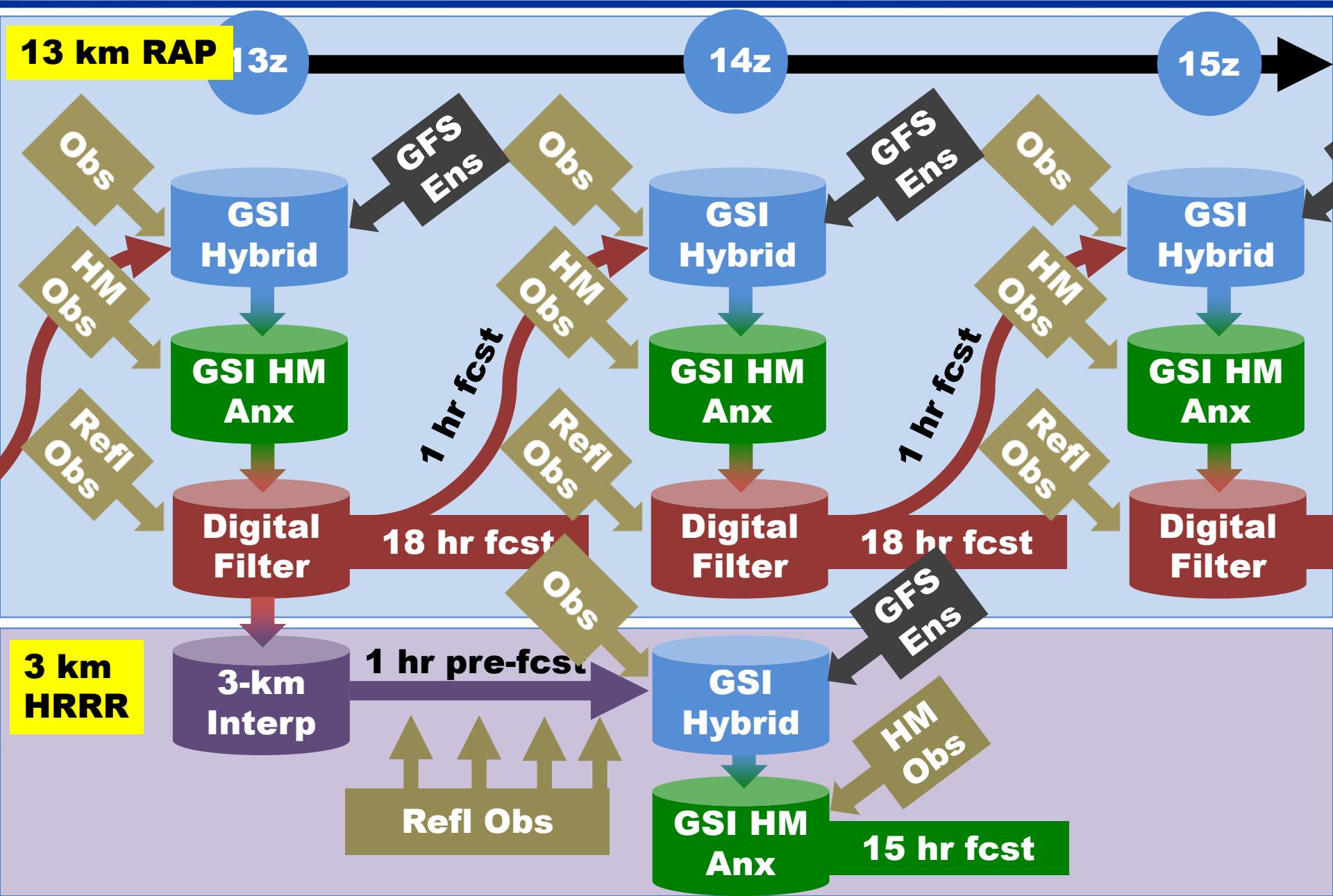


HRRRv1 Initialization from RAPv2



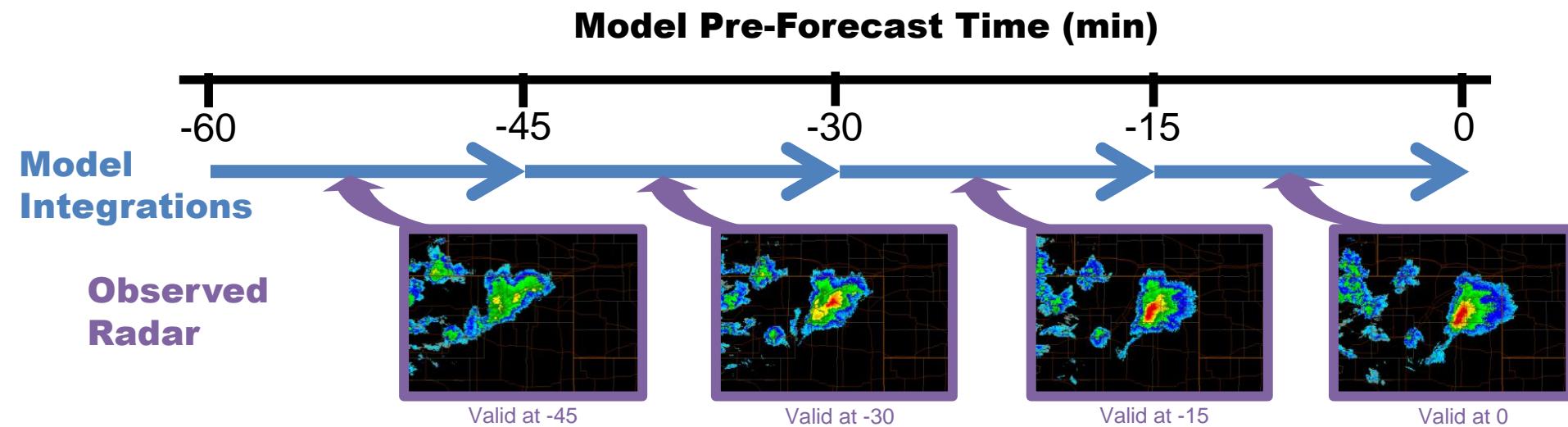


HRRRv2 Initialization from RAPv3





Sub-Hourly MRMS Radar Reflectivity Use



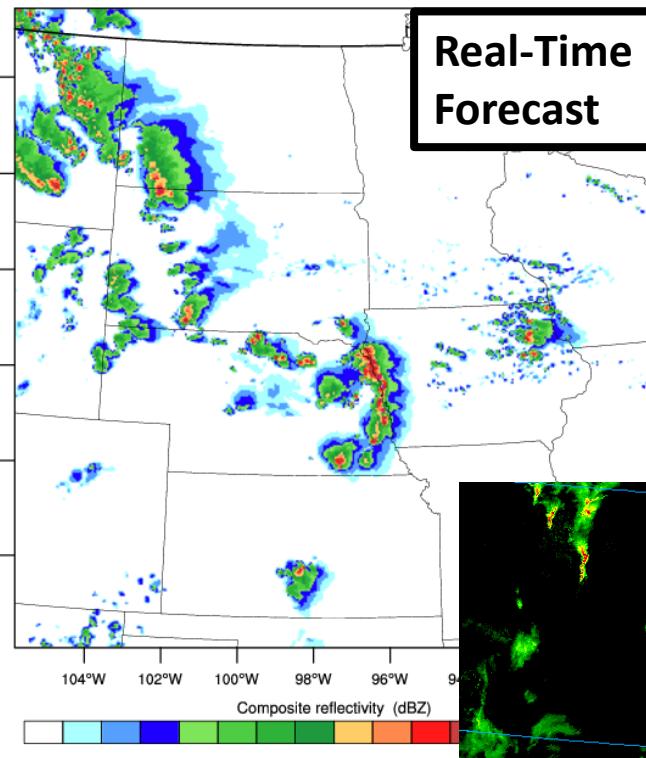
During the 1-hour pre-forecast, reflectivity observations are used to specify latent heating rates in each previous 15-min period:

- Observed Reflectivity ≤ 0 dBZ : Zero heating rate to suppress spurious model precipitation.
- 0 dBZ $<$ Observed Reflectivity $<$ 28 dBZ : Model microphysics heating rate preserved.
- Observed Reflectivity ≥ 28 dBZ : Positive heating rate to promote convective development.
- No radar coverage: Model microphysics heating rate preserved.



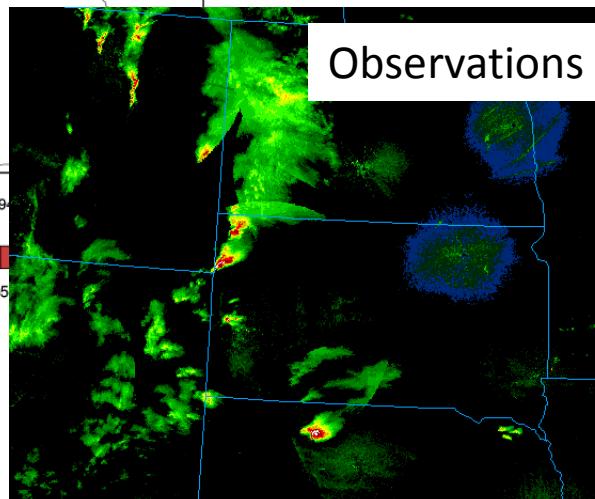
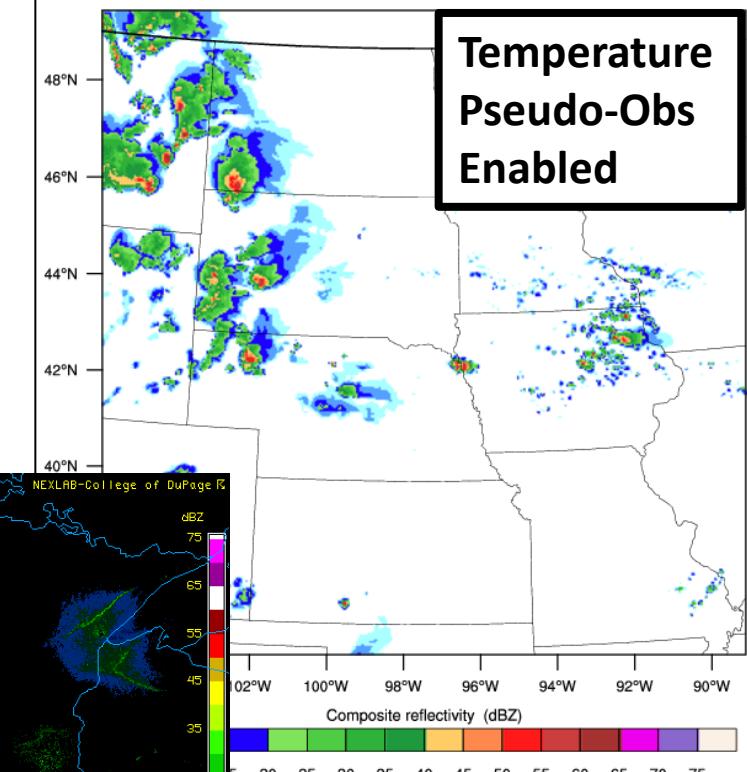
Convective Evolution 17 June 2014

Composite reflectivity (dBZ)



00 UTC
18 June 2014
Coleridge, NE

Composite reflectivity (dBZ)



Control run develops too much high-based convection that grows upscale
Data assimilation change improves timing and evolution of convection

Summary: RAPv3/HRRRv2 vs. RAPv2/HRRRv1

Winds – Substantial RAPv3 improvement for both upper-air and surface, for all seasons (will benefit turbulence fcsts also).

Temperature/Dewpoint – Reduced low-level warm/dry bias. Improved upper-level temp/RH fcsts.

Ceiling – Improved detection from physics changes and new cloud-fraction diagnostic.

Convection – Much improved storm forecasts and convective environment.

Icing – Improved cloud/ supercooled liq water

Contributions from physics // DA

XXX	XX
XXX	XXX
XXX	XX
XXX	XX
XXX	X

RAPv3/HRRRv2 changes to model physical parameterizations

- Substantial for some parameterizations (MYNN PBL, RUC LSM, Thompson cloud)
- Major impact on forecast accuracy
- PBL, cloud, LSM, rad work in concert (successful co-development for HRRR/RAP)



RAP/HRRR Implementation Map

ESRL – experimental version

- RAPv3 – GSD testing in 2014
 - Will initialize 2014 ESRL-HRRR(v2)
 - Improved PBL, LSM, cu-parm, DA
 - WRFv3.6.1 w/ Thompson/NCAR aerosol-aware microphysics
- HRRRv2 – GSD testing in 2014
 - Initialized by 2014 RAP (v3)
 - Improved radar assimilation, hybrid assimilation, PBL/cloud physics
- RAPv4 – GSD testing in 2015
 - Hourly RAP ensemble data assimilation
- HRRRv3 – GSD testing in 2015
 - Target: Improved 3km physics + improved data assimilation.

NWS-NCEP - operational

- Implement Q3 2015
- Implement Q3 2015
- Implement 2016
- Implement 2016

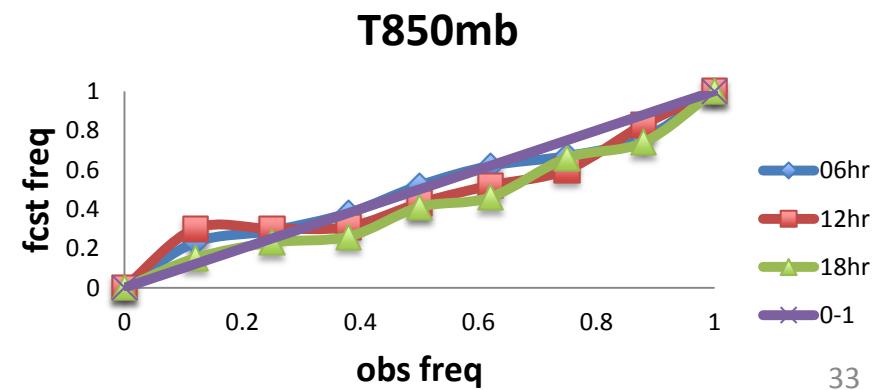
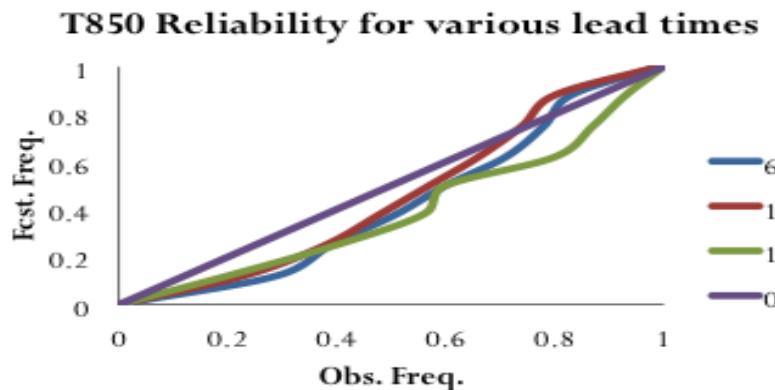


Initial Testing toward NARRE

Current Configuration

	MP	Sfclay	Sfcphy	PBL	CU	IC/LBs
Ctl rap	Thompson	MYNN	RUC	MYNN	GF	GFS
rap1	Thompson	MO-MYJ	RUC	MYJ	BMJ	GEP01
rap2	Ferrier	MO-MYJ	RUC	MYJ	BMJ	GEP02
rap3	Ferrier	MYNN	RUC	MYNN	GF	GEP03
Ctl nmmmb	Ferrier	MYJ	NOAH	MYJ	BMJ	GFS
nmmmb1	Ferrier	MYJ	NOAH	MYJ	BMJ	GEP01
nmmmb2	Ferrier	MYJ	NOAH	MYJ	BMJ	GEP02
nmmmb3	Ferrier	MYJ	NOAH	MYJ	BMJ	GEP03

**Work by
Isidora
Jankov**



NOAA hourly updated modeling

Feb 2014 – Rapid Refresh v2 – oper at NCEP

→ Improved surface forecasts,
convective environment fields

- Hybrid ensemble-variational GSI assimilation
- Model – improved cloud / PBL / LSM / soil,
updated version of WRF ARW

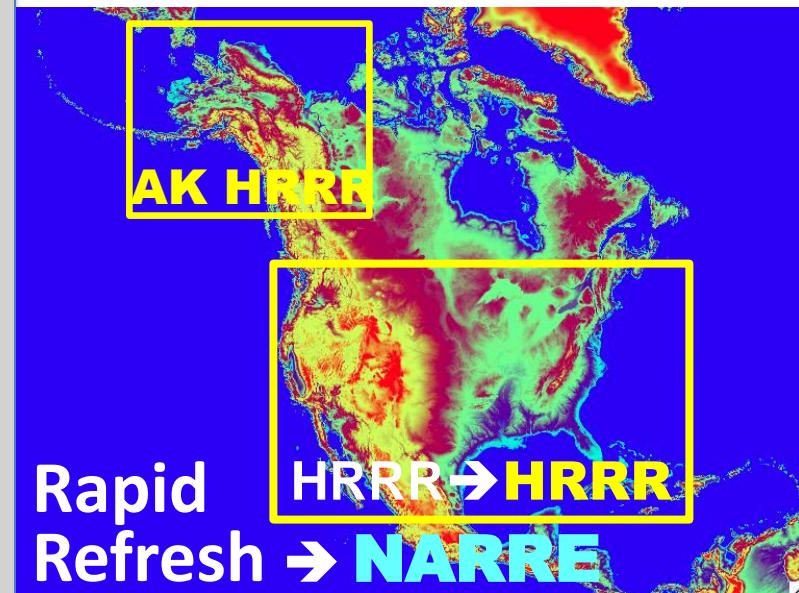
Sept 2014 – HRRR (3km) – oper at NCEP

→ Hourly updated storm-scale forecasts,
greater accuracy (timing, location, structure)
for thunderstorms and many other features

- 3-km / 15 min radar reflectivity assimilation

North American Rapid Refresh Ensemble (NARRE)

- 2 cores (ARW, NMMB), 6 members
- Hourly updating with GSI-hybrid EnKF
- Hourly forecasts to 24-h, 84-h 4x / day



Future oper @ NCEP

2015 – RAPv3/HRRRv2

- ~2017 – NARRE
- with hybrid 4d-ens/var DA
- ~2019 – HRRR Ensemble
(HRRRE) – eventually
with ~3km ensemble DA

